THE UTILIZATION OF CALCIUM COMPOUNDS IN ANIMAL NUTRITION

OHIO
Agricultural Experiment Station

WOOSTER, OHIO, U. S. A., MARCH, 1921

BULLETIN 347

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BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 347 MARCH, 1921

1. THE METABOLISM OF CALCIUM COMPOUNDS BY GROWING SWINE—I

The metabolism of swine is a matter of unusual interest because of their great economic importance; also on account of the prevailing practice of feeding swine on expensive concentrated feeds; further, because the feeds most used are peculiarly deficient in certain essential nutrients; and again, because swine are by nature adapted to the same general character of diet as are human beings, so that the results of investigations on the metabolism of swine have a more direct bearing upon human nutrition than do the results from studies on other farm animals or the smaller animals which are commonly used for laboratory investigations.

The subject of mineral nutrients for animals in general has many points of interest, but like other factors of imperative importance, the main requirements are necessarily met by ordinary practice. The details of these nutritive requirements must be understood, however, especially of the optimum conditions for growth.

The basis of special interest in the feeding of calcium compounds to swine is that pigs very often suffer fracture of bones or rupture of tendinous attachments during shipment to market, and brood sows frequently break down or become inactive as a result of insufficient mineral nutriment. These troubles are not uncommon among swine kept in close quarters, but are almost unknown when they have adequate range.

Our approach to this study has been through previous work which the present investigation logically follows. The first of these experiments, an extensive study of the mineral metabolism of swine, was published as Ohio Bul. 271. In this work five pigs, all barrows and litter mates, were taken through eight experimental periods of 10 days each, separated by 7-day intervals. Complete balance data were secured on eight chemical elements, and other related observations were recorded. The rations used in these studies were all based upon corn or other cereal foods and the more highly nitrogenous supplementary products which are most commonly fed to swine.

This investigation, considered in connection with certain earlier work, especially that of Weiser,* and with the facts as to the composition of feeds, made it clear that no ration of grains, grain products or other seeds can sustain anything approaching maximum growth of the skeleton of swine. But from rations containing milk, and others containing meat meal (including considerable amounts of bone), these pigs stored from nine to ten times as much calcium as from the best one of the rations composed exclusively of seed products. The results directed attention in an emphatic way to the content of foodstuffs in those elements which compose the skeleton, and numerous points as to the interrelationships of the mineral elements in metabolism were recorded.

A second contribution to the same subject, by a different method of attack, is reported in Ohio Bul. 283. This paper records results of a feeding experiment with 35 pigs, extending over a period of 84 days, and terminating in a study and analysis of the carcasses. The rations used, largely the same as in the metabolism study above mentioned, were corn alone, and corn supplemented by soybeans, linseed oilmeal, wheat middlings, tankage (meat meal), and skimmilk. This study revealed a definite specificity in the effects of the rations regarding many details of composition and development, among which were the proportions of protein, fat and ash in the carcasses, the relative proportions of skeleton and flesh, and numerous observations as to the composition of the bones. This experiment confirmed the preceding one in emphasizing the inadequacy of rations composed of cereals and other seed products to produce normal growth of bone. The skeleton was shown to be highly responsive to the character of the ration, as evidenced by its composition, and many instances of acute pathological condition of the bones, due to mineral insufficiency of certain of the rations, were observed in the study of the carcasses.

A third study, on the metabolism of organic and inorganic compounds of phosphorus, also conducted with swine, and extending through several years, was reported as Ohio Tech. Bul. No. 6. This work shows that any such supplemental phosphorus as is to be added to the rations of farm animals may advantageously be added

*Biochem Zeit 44 (1912), 279 289

as inorganic phosphates. Useful distinction is here made between primary pharmacologic and final nutritive effects of inorganic phosphates.

The fact that simple inorganic salts of calcium are assimilable by animals has been generally understood for many years. There are important practical aspects of the matter of feeding such compounds to farm animals, however, which have not been adequately considered, and ill-advised recommendations of feeding practice pass current in our agricultural journals. It has seemed desirable, therefore, on account of the importance of this matter in relation to growing swine and to lactating sows, that we determine by critical experiment the form and manner in which mineral supplements may most advantageously be fed.

The particular object of this study was to determine the character of the mineral metabolism as affected by the several calcium phosphate and carbonate preparations fed. On certain accounts our plan of investigation was not such as to afford a basis for close quantitative comparisons between the mineral supplements; thus the live weight varied from period to period, and the mineral intake was not maintained uniform in relation to live weight. Since the mineral requirements of swine have not been definitely determined, and since they do not vary directly as the live weight, our most satisfactory basis for quantitative comparisons between mineral supplements consists of results from experiments in which each of the supplements to be compared is fed to a lot of pigs of the same live weight. This kind of evidence can be obtained more practicably from experiments conducted in the feed-lot than from metabolism investigations.

In this experiment, which was conducted during November and December, 1917, five pigs, all purebred Poland China barrows, were taken through three 10-day balance periods, separated by 7-day intervals during which the subjects were accustomed to the rations of the following experimental period. The first collection period began on November 3, and the last ended on December 18. Two rations were used in each test period, three pigs on one, and two on the other; our results, therefore, so far as the feeding is concerned, were either in duplicate or in triplicate. Our previous work, in which five pigs were given the same treatment, showed that so great a number of subjects was not necessary in investigation of just this nature.

The rations used were the following:

1. Basal ration alone; corn meal 350 parts, wheat middlings 50 parts, linseed oilmeal 50 parts, and common salt 1 part.
2. Same, plus powdered limestone (limestone floats).
3. Same, plus precipitated bone flour.
4. Same, plus rock phosphate floats.
5. Same, plus "special" steamed bone flour.
6. Same, plus precipitated calcium carbonate.

Pigs 1, 2, 3, in the course of the three periods, received rations 1, 3 and 5, while Pigs 4 and 5 received rations 2, 4 and 6.

The powdered limestone was prepared by stirring up agricultural limestone in water, pouring off the suspended matter, and allowing to settle and to evaporate. From the method of preparation it will be understood that the product was very finely divided.

The precipitated bone flour was the commercial product—a hydrochloric acid extract of bone, neutralized and precipitated with milk of lime, and washed practically free from chlorides. It is a mixture of dicalcic and tricalcic phosphates, with the former predominating. The rock phosphate floats was the unacidulated product as applied to the land for fertilizing purposes. The "special" steamed bone flour was of a fineness designated "bone floats."* The calcium carbonate was a precipitated product of commercial grade.

This experiment furnished a basis for the comparison of these three forms of calcium phosphate and two forms of calcium carbonate. Each of these preparations, except the precipitated carbonate, was fed in a quantity providing approximately 5 grams of calcium per pig per day.

The observations covered (1) the usual proximate analysis of foods and feces, to check the effects of the mineral supplements on the digestibility of the rations; (2) daily estimations of ammonia and acidity in the urine, as measures of the acid-base balance in the organism, and (3) complete balance determinations on sodium, potassium, calcium, magnesium, sulphur, phosphorus, chlorine and nitrogen.

METHODS OF EXPERIMENTATION

The metabolism crates used were as illustrated in Ohio Technical Bulletin No. 6, and as illustrated and described in Ohio Bulletin 271. The daily routine was as described in our earlier published work. The pigs were fed twice daily; the feeds mixed, weighed out into portions and sampled for analysis at the

Throughout this series of papers the term "special" steamed bone signifies not packer's steamed bone but a refined product from gelatine manufacture which is characterized by comparative freedom from impurities and odor beginning of each experimental period; the feces marked with carmine (1 gram per pig); the urines preserved with a 10 percent solution of thymol in chloroform (3 to 5 c. c. per 2.5 liter bottle), and refrigeration at approximately 34-36 degrees Fahrenheit; the feces preserved by refrigeration at a temperature close to zero, Fahrenheit. The screens upon which the pigs stood were brushed daily, and scrubbed at the beginning and end of each period. The urine cloth was washed daily in boiling distilled water, as also the lower screen and urine hopper. This washwater was filtered and added to the urine sample, of which aliquots were preserved each day. Aliquots for the estimation of acidity and ammonia were taken daily from the undiluted urine, before the addition of the wash-water. The pigs were scrubbed daily with distilled water containing phenol.

Chemical analyses were made in triplicate, by the following methods:

Moisture: On feeds and feces, vacuum method, drying to constant weight over sulphuric acid; on mineral supplements by drying to constant weight in hot air oven at 105 degrees C.

Nitrogen: On feeds and feces, Kjeldahl-Gunning-Arnold method; on urine, method in Hawk's Practical Physiological Chemistry, 5th edition, p. 483.

Ether extract: Continuous ether extraction, in alundum capsules, for 100 hours.

Ash: Gentle ignition below dull redness, with leaching and filtration if necessary, or with mere moistening of the charred mass and continuance of gentle ignition.

Crude fiber: To a 2-gram sample of feed or feces add 200 c. c. of 1.25 percent boiling sulphuric acid; boil for 30 minutes, keeping volume constant by addition of water; then add 200 c. c. of 3.52 percent boiling sodium hydrate solution, and boil 30 minutes. Remove alkaline solution by inverse suction through fine linen wired over a carbon funnel, with a filter flask interposed between funnel and suction pump. Wash with hot water until this comes through fairly clear. Render the solution containing the fiber acid to litmus by adding 2 to 4 c. c. of 1.25 percent hydrochloric acid, and allow to stand over night. This tends to harden the fiber. Filter through Gooch crucible and wash with hot water until free from chlorides, then with alcohol and ether. Dry to constant weight, ignite and weigh. The difference in weights represents crude fiber.

Carbohydrates: By difference.

Urinary ammonia: Folin method as modified by Steele.

Urinary acidity: Folin method, by titration with tenth-normal sodium hydroxide, with phenolphthalein as an indicator, and using potassium oxalate.

Sodium: Official method, modified; weighing as combined sulphates; sodium sulphate determined by difference; modifications to be published.

Potassium: Calcium and phosphorus first removed, separately in mineral supplements; in rock phosphate floats and in bone preparations, phosphates were precipitated three times according to suggestion of P. L. Hibbard.† In feeds low in calcium but high in phosphorus sufficient calcium was added to combine in maximum proportion with phosphorus present. The estimation was made by the official Lindo-Gladding method.

*Journ. Am. Chem. Soc. XLI (1919), 440.
†Journ. Indus. and Eng. Chem. IX (1917), 505.

Calcium: McCrudden method, modified to use potassium permanganate titration.*

Magnesium: To filtrates from calcium estimation in casseroles on steam bath add 20 c. c. concentrated nitric acid, followed later by 15 c. c. concentrated hydrochloric acid; evaporate to small volume and transfer to 60 c. c. evaporating dishes; evaporate to dryness, ignite, dissolve in 10 percent hydrochloric acid, and filter. Magnesium is estimated by the usual method, weighing as the pyrophosphate.

Sulphur: Sodium peroxide method, as modified by Krieble and Mangum.†

Chlorine: Official Volhard method, ashing in presence of sodium carbonate. The use of twentieth-normal silver nitrate was found advantageous.

Phosphorus: A charge sufficient for sodium, potassium and phosphorus estimations was digested with nitric and sulphuric acids. With feeds and feces add hot water to the Kjeldahl flasks containing the charges to facilitate disintegration; follow with 20 c. c. concentrated nitric acid, shake occasionally and allow to stand over night. (This prevents foaming.) Add 20 c. c. of the following mixture and digest over free flame.

Concentrated sulphuric acid, 600 c. c.
Concentrated nitric acid, 800 c. c.
Red fuming nitric acid, 400 c. c.

Digest, cool, dilute, filter into a 250 c. c. volumetric flask, make up to volume, and determine phosphorus on an aliquot by the gravimetric method.

BEHAVIOR OF EXPERIMENTAL SUBJECTS

The experiment progressed from beginning to end without disqualifying irregularities, except that Pig No. 2 was on a reduced ration during the last 5 days of Period III. This pig received steamed bone flour as a supplement. With this exception no change in amount of feed was made during any experimental period.

At the beginning of the experiment the pigs were given nearly a full feed of the ration, but, as is usual in such investigations, it was not found practicable to make regular increases in the feed as the experiment progressed. As the pigs gained in weight, the food consumption remaining about stationary, the amount of feed per unit of live weight fell from about 95 to about 65 percent of a full feed. The average increase in live weight during the experiment was 1.4 pounds per head per day. The growth, therefore, was a normal response to the amount of feed consumed.

MINERAL BALANCES

From the live weights as recorded in Table I, page 21, it will be noted that Pigs 4 and 5 were distinctly smaller than Pigs 1, 2 and 3. This fact should be borne in mind in studying the balance data.

*Journ. Indus. and Eng. Chem. XII (1920), 77.
†Journ. Am. Chem. Soc. 41 (1919), 1317.

The amount of common salt fed was one gram in each 451 grams of the basal ration. From the balance data in Tables VI, VII and VIII and the intake and retention per kilogram of live weight in Table IX, pages 26 to 29, it will be noted that the retention of sodium was consistent and considerable in all cases. The amount of sodium in the ration was unquestionably sufficient, and there were no fluctuations in the retention of sodium which could be related to the calcium preparations fed.

As to chlorine, there was one negative balance, and one case of retention of only 0.087 gm., both with Pig 2; otherwise the retention was always considerable in amount, though in each of the 15 balances the retention of chlorine was less than the retention of sodium. The retention of chlorine was quite variable. In our studies of the mineral metabolism of the milch cow (Ohio Bul. 295, 308 and 330) there is also evidence suggesting that the chlorine requirement of animals may not be so fully satisfied by the feeding of a given amount of common salt as is the coincident sodium requirement. Chlorine, because of its very ready solubility, is an especially mobile element, and its retention appears to be affected by a great diversity of conditions. Salt, in the proportion fed, furnished 75 percent of the chlorine and 60 percent of the sodium of the entire ration, including the salt. One gram of salt per pound of dry feed, or 3.5 ounces per 100 pounds of feed, then, seems to be sufficient for growing swine.

Potassium was retained in each of the 15 balances, the maximum retention being 2.35 grams and the minimum 1.05 grams. The content of the rations in this element was in all cases superabundant. Its retention was not shown to be affected by the calcium supplements. Table IX, page 29, shows that the retention of sodium and potassium per kilogram of live weight was almost exactly the same in five cases out of six, though the intake of potassium was relatively much greater than of sodium.

Calcium was eliminated in amounts greater than the intake by each pig on the basal ration (Pigs 1, 2 and 3, Table VI). With an intake of 20.8 milligrams of calcium per kilogram of live weight there was a loss of calcium equivalent to 30.4 percent of the intake. In the light of these results on growing pigs it is obvious that such a grain ration is especially inadequate for a sow during milk production; and the breakdown of sows suckling pigs in close quarters requires no further explanation. This observation is not new, however, either in our own work or in the literature. More extensive mineral balance data on common swine rations may be found in Ohio Experiment Station Bulletin 271.

Pigs 4 and 5 in Period I, page 26, were fed on the same basal ration as Pigs 1, 2 and 3, but with the addition of 14.038 grams per head daily of limestone floats, containing 4.948 grams calcium. The effect upon calcium retention is phenomenal. These pigs retained 2.7 times as much calcium as the entire content of the basal ration of this element (exclusive of the limestone), and approximately 50 percent of the entire intake.

In Period II, page 27, Pigs 1, 2 and 3 received 4.973 grams calcium in the form of precipitated bone flour. This readily-soluble preparation was retained in larger amount than was the limestone floats (Pigs 4 and 5, Period I, page 26), and in larger proportion of the intake (Table IX, page 29), but in slightly smaller amount per kilogram of live weight. The retention averaged 3.527 grams.

Pigs 4 and 5 received rock phosphate floats, equivalent to 5.106 grams calcium, with the result that the calcium retention, as compared with that of the same pigs in the preceding period (limestone floats), decreased 27 percent, from 3.025 to 2.204 grams. The calcium of the rock phosphate was decidedly less available than was that of the limestone floats, and, comparing with results from Pigs 1, 2 and 3, only 62 percent as much calcium was retained from the ration containing the rock phosphate as from the ration containing the more readily-soluble precipitated bone flour.

In Period III, page 28, Pigs 1 and 3 received 5.147 grams calcium in the form of steamed bone flour, while Pig 2, on account of a necessary reduction in ration during the last 5 days of the period, received only 4.22 grams. Omitting Pig 2, the absolute retention was not quite equal to that from the precipitated bone flour, and the retention per kilogram of live weight was 24 percent less. Pigs 4 and 5 received precipitated calcium carbonate. It was intended to feed an amount sufficient to furnish 5 grams of calcium, but through error the amount fed contained 6.122 grams. The data in Table IX, page 29, however, show that two other lots received as much calcium per kilogram of live weight as did this lot which was fed the carbonate. The calcium retention from this precipitated carbonate was greater than from any other supplement.

In our judgment the most critical evidence as to the comparative values of the calcium compounds fed is the retention of calcium per kilogram of live weight, as set forth in Table IX, page 29. From this point of view the rock phosphate floats appeared to be much the least efficient. Attention is called to the comparatively low intake of steamed bone flour, per kilogram of live weight. This may have served to restrict calcium retention.

The magnesium balances were of the same sign as the calcium balances, whether positive or negative, in 13 cases out of the 15, and the circumstances connected with the other two cases are such as to carry little weight against the prevailing agreement. There were extensive negative balances on the basal ration alone, without calcium supplements (Pigs 1, 2 and 3, page 26). There was also slight loss with two of the pigs receiving steamed bone flour (Pigs 1, 2 and 3, page 28). In one of these two cases there was practically a magnesium equilibrium, and in the other the loss, only 0.049 gram, was in part due to the feed reduction which was necessary. Except with Pigs 1 and 2, Period III, and with Pigs 1, 2 and 3 in Period I, there was magnesium storage. Table IX, page 29, shows that those supplements from which calcium was retained most efficiently induced the largest retention of magnesium, per kilogram of live weight.

As compared with the basal ration alone, the rations containing the mineral supplements, whether these supplements contained phosphorus or not, all caused great increase in the phosphorus retention; that is, phosphate and carbonate as well improved the status of the phosphorus balance. This is clearly due to the limitation in the retention of phosphorus imposed by the deficient calcium content of the basal ration. Since the phosphorus content of the body, and of the skeleton, is so much greater than the magnesium content, the effect of calcium to improve phosphorus retention is much more pronounced than is its effect to increase magnesium storage.

The sulphur and nitrogen balances were all positive, normal and consistent. The metabolism of these elements, signifying protein metabolism, was, as expected, not demonstrably affected by the mineral metabolism. While a certain measure of dependence of mineral metabolism upon protein metabolism would doubtless become apparent in the course of time it would not be expected to be noticeable in a short balance period. The metabolism of sulphur and nitrogen was apparently determined by the intake of these elements and by the synthesis and repair of nitrogenous tissue. The facts regarding the nitrogen metabolism may be conveniently ascertained by an inspection of Table XIV, page 34.

The chlorine intake was generally sufficient, since there was but one negative balance among fifteen. On account of the neutral reaction and great solubility of the chlorides, and the fact that no great quantity of chlorides can be stored in the organism, the balance data do not exhibit marked peculiarities of interrelationship with other elements. The storage of chlorine was increased, however, by each of the mineral supplements fed, but especially by precipitated bone flour.

The balances of sodium, potassium and sulphur appeared not to be affected by the calcium-containing preparations fed.

In general the significance of mineral balance data varies in accord with the amount of the element contained in the body or utilized in body processes; and the elements, the compounds of which are the less soluble, exhibit the more marked features of interrelationship. On account of the number and complication of the functions of the mineral elements in work of construction and regulation within the animal body it is impossible from data on income and outgo alone to demonstrate any but the more obvious of the interrelationships of these elements, especially of those involved in the smaller amounts.

Tables X, XI and XII, pages 30 to 32, exhibit the amounts of feeds consumed, stated in pounds, for the convenience of those who are accustomed to think in these terms, with the balance data abbreviated by the omission of the figures for the excreta.

ACID-BASE BALANCE IN THE ORGANISM

Table XIII, page 33, sets forth the daily and average data on ammonia and acidity of the urine. These figures show that the limestone and the precipitated carbonate fed to Pigs 4 and 5 in Periods I and III rendered the acidity of the urine lower and the amount of ammonium salts less than in Period II when the rock phosphate floats was fed; and the data for Pigs 1, 2 and 3, Period II, show that the addition of precipitated bone flour increased the urinary acidity and ammonium salts to figures exceeding those obtained from the basal ration alone (Period I); while the change from precipitated bone flour to steamed bone flour (Period III) again lowered the figures for ammonia and acidity to a level not very different from that existing during Period I on the basal ration. Pig 2 in Period III should not be included in this comparison, as the reduced feed consumption and irregularity of behavior during the latter part of the period reflects itself in figures diverging somewhat from the others in the same group.

The effect of the precipitated bone flour to increase acidity and therefore ammonia in the urine is due to the large proportion of dicalcic phosphates contained in this preparation. That portion of the phosphorus of the precipitated bone flour which was eliminated in the urine required for its neutralization a greater amount of base than accompanied it in this preparation. Then the steamed bone flour contained a certain amount of carbonate which served, in a measure, to reduce urinary acidity and ammonia. The effect of calcium carbonate to reduce the proportion of ammonia nitrogen in the total urinary nitrogen is shown especially clearly in the fourth column of figures in Table XIV, page 34.

Later work in this laboratory* has shown that the alkali reserve of the blood plasma of swine may be significantly increased by feeding the potentially basic precipitated calcium carbonate, or decreased by feeding the potentially acid precipitated bone phosphate, when these substances are fed as suppelments to a ration of corn, linseed oilmeal and wheat middlings in quantities furnishing 200 milligrams of calcium per kilogram of live weight.

Since these variations would in all probability be followed, in time, by like variations in the other alkali reserves of the body, it is more than likely that changes of body function would result Evidence is lacking, however, as to the final physiological and practical significance of these facts.

COEFFICIENTS OF DIGESTIBILITY OF RATIONS

Table XVI sets forth the coefficients of digestibility of the nutrients of the rations. Metabolic nitrogen was not estimated. The data reflect some individual differences between the animals, and probably some adaptation to the close confinement of the metabolism crates. In our judgment they do not indicate significant effects of the mineral supplements on the digestibility of the rations.

PARTITION OF OUTGO OF ELEMENTS BETWEEN URINE AND FECES

A statement of the percentages of the elements leaving the body by the urine and by the feces compose Table XV, page 35.

Of the sodium leaving the body about one-third was contained in the urine and two-thirds in the feces. The partition was not affected in notable manner by the mineral supplements.

Potassium was usually eliminated in the urine in proportions varying between one-third and one-half of the total outgo. The proportion of the potassium exceeded the proportion of the sodium eliminated in the urine in 11 cases out of 15; and the potassium in the feces exceeded the potassium in the urine in 14 cases out of 15.

*Forbes, E. B., Halverson, J. O., and Schulz, J. A., J. Biol. Chem. XLII, 459-463; reprinted as No. 6 in this series of papers.

The calcium distribution tended strongly toward uniformity. The proportion in the urine varied between 3.98 and 8.13 percent of the total outgo.

The magnesium partition likewise varied but little, the range being from 6.55 to 14.54 percent of the total outgo, in the urine.

The sulphur partition also was remarkably uniform, the proportion eliminated in the urine being 52.94 to 60.26 percent of the total outgo.

Chlorine was present in the urine to the extent of 88.65 to 94.63 percent of the outgo.

The partition of phosphorus varied in a marked and consistent manner. The urinary phosphorus varied between 2.33 and 37.05 percent of the outgo. The carbonate had a pronounced effect to deflect phosphorus from urine to feces, because of the low solubility of phosphates in alkaline or almost neutral urine. The phosphorus of the ration containing the precipitated bone flour was eliminated in the urine in larger proportion than that from any other ration. This was the most acid ration, containing the maximum intake of phosphorus, and with the phosphorus to a considerable extent in the dicalcic form. The phosphorus of the ration containing the steamed bone flour was eliminated in the feces to a greater extent than was that from the ration containing the precipitated bone flour.

Of the outgoing nitrogen 55.35 to 68.39 percent was in the urine; that is, more than half of the nitrogen eliminated left the body by this route. The proportion of the nitrogen excreted in the urine was distinctly higher with the ration containing the steamed bone flour than with any other.

In order to ascertain the significance of this fact certain data applying to Pigs 1, 2 and 3 in Period II and Pigs 1 and 3 in Period III are tabulated for comparison. Pig 2 in Period III is omitted from this comparison since an enforced feed reduction with this pig reduced the value of the results for this purpose. The data as presented are averages for three pigs in Period II and two pigs in Period III.

DATA RELATIVE TO NITROGEN METABOLISM OF PIGS RECEIVING PRECIPITATED BONE AND STEAMED BONE FLOUR

Supplement received	Average weight of pigs	Intake	Urine	Feces	Retention	Digestibility
	Kilograms	*Grams*	*Grams*	*Grams*	*Grams*	*Percent*
Precipitated bone flour... .	71.083	43.122	18.677	12.264	12.181	71.60
Steamed bone flour	85.400	42.985	22.578	11.201	9.207	73.87

The high urinary outgo, high digestibility and low retention of nitrogen with the pigs receiving the steamed bone flour signifies, in our opinion, deflection of protein from synthesis to energy production, as necessitated by the stationary feed and nitrogen intake coincident with considerable gain in live weight. It was impossible to increase the feed of the pigs which received the steamed bone flour. The disadvantage of stationary feed intake was felt more keenly by Pigs 1, 2 and 3, which received the steamed bone flour, than by Pigs 4 and 5, because the latter, which were smaller pigs, received a somewhat more liberal feed allowance per unit of live weight.

The earliest metabolism data which have come to our attention in which a comparison has been made of the availability to swine of the constituents of various calcium-containing preparations are those published by Hart, McCollum and Fuller as Wisconsin Research Bul. No. 1, 1908. In this investigation attention is centered especially upon phosphorus metabolism, and a comparison was made of bone ash, rock phosphate floats and a precipitated phosphate containing 70 percent dicalcic and 30 percent tricalcic phosphates.

The daily retention of phosphorus from the three rations was as follows:

Rock phosphate floats (7 days), 1.4 to 3.11 gm., average 2.35 gm.
Bone ash (6 days), 0.94 to 2.17 gm., average 1.54 gm.
Precipitated phosphate (5 days), 1.80 to 3.07 gm., average 2.22 gm.

One pig was used on each ration. The basal ration, composed of washed bran, wheat gluten and rice must have been very low in calcium, lower than any normal ration, and so low that the calcium content of the supplements fed would influence greatly the extent of the phosphorus retention; and since the floats in addition to having the main part of its phosphorus in the tricalcic form probably contained additional calcium as the carbonate, while the precipitated phosphate was largely dicalcic, conditions were relatively unfavorable for phosphorus retention from the latter.

Among the authors' conclusions was the following: "The more insoluble floats did not fail to supply the required phosphorus, but appear in every way to have been as efficient as precipitated phosphates for these animals." Since only one pig was used on a ration, and the collection periods were short, and the basal ration was abnormally low in calcium it was felt that further data on this subject were desirable.

The balance data of Period II of this study, page 27, exhibit marked and consistent differences in the metabolism of rock phosphate floats and precipitated calcium phosphates. The calcium and phosphorus of the ration containing the precipitated bone flour were retained in amounts 60 percent and 53 percent, respectively, greater than from the ration containing the rock phosphate floats.

Weiser* first showed that growing swine on rations of corn alone were unable to maintain calcium equilibrium, and that the phosphorus balance was either negative or the retention distinctly subnormal. He also showed that calcium carbonate added to a ration of barley alone would increase the retention of both calcium and phosphorus. Weiser concluded that magnesium retention was decreased by the feeding of calcium carbonate. The balance data of our study, however, make it clear that the magnesium retention was increased by both forms of calcium carbonate, and both phosphate preparations as well.

In 1914 Hart, Steenbock and Fuller† reported a similar investigation, using a basal ration of corn and gluten feed, to which was added calcium carbonate and tricalcic phosphate, in successive periods. Calcium was lost on the ration of corn and gluten feed, and, as in Weiser's work, the retention of both calcium and phosphorus was increased by both the carbonate and the phosphate.

The authors regarded the negative balance from the corn ration as "probably abnormal," and, "a result of nutritive disturbances which are met with occasionally in metabolism work and in this case were indicated by a noticeable restlessness of the animal and the excretion of exceedingly hard and dry feces." The work of Weiser had already shown, and the work of this laboratory has confirmed Weiser's finding, that the calcium balance is normally negative when growing pigs are fed on corn alone.

In a second experiment, with a ration of corn, oats and gluten feed, the addition of calcium carbonate and of rock phosphate floats again both increased the retention of calcium and of phosphorus.

In a third experiment rock phosphate floats was added to a normal grain ration composed of wheat middlings, corn, oats and linseed oilmeal. The calcium retention was shown to be increased thereby. This work confirmed by balance experiment the observation which had been made by several investigators that calcium-containing preparations added to normal grain rations would be assimilated, as evidenced by the increase in the ash and strength of the bones.

*Biochem. Zeit. 44 (1912), 279-289.
†Wis. Agr. Exp. Sta. Research Bul. 30, 1914.

Another publication, of the same date, by Forbes, Beegle, Fritz and Menching* reported a comprehensive series of balance experiments on seven common swine rations. The results were based on records from five individuals. No mineral supplements, other than common salt, were used, but the data bear on the present investigation as they emphasize the significance of the calcium insufficiency of grain rations generally, and as they confirm Weiser's finding of negative calcium balances on the ration of corn alone. It was also noted that a wide range of variation in balance between mineral acid and basic elements characterized this group of common rations. This factor, however, appeared not to affect calcium retention. The calcium intake was considered to predominate in determining the extent of the calcium retention.

Lamb and Evvard† have conducted a recent study on acid tolerance in swine, using basal rations to which mineral and organic acids were added directly. Their main finding was that, "On neither ration did the mineral acid cause a significant loss of calcium, nor did it interfere with the storage of protein."

From the data of Experiment I, page 337, we compute that the apparent decrease of calcium retention, due to sulphuric acid fed, was 21 percent on the basis of the amount retained, and 25 percent on the basis of proportion of the intake retained. In consideration of the very high calcium content of the rations this decrease of retention seems important. The true significance of the results is clearly evident when they are computed to the kilogram live weight basis, as below.

DATA OF LAMB AND EVVARD COMPUTED TO DAILY INTAKE AND RETENTION OF CALCIUM PER KILOGRAM OF LIVE WEIGHT

Period	Treatment	Intake	Retention	Proportion of intake retained
		Grams	*Grams*	*Percent*
I	Control	0 235	0.083	35.4
III	Sulphuric acid	0.213	0.054	25.4
V	Control	0.184	0.059	32.3

The fact that the percentage of the intake retained in the second control period is so nearly as great as in the first control indicated that the decreasing rate of intake, as related to live weight, was probably not much, if any, below the optimum, in the second control period.

*Ohio Agr. Exp. Sta. Bul. 271, 1914.
†Journ. Biol. Chem. 37 (1919), 317-342.

In Experiment II it seems to us that the basis for judgment did not warrant conclusions as to the effect of sulphuric acid ingestion on calcium retention, because of the lack of intermediate periods and the lack of agreement in the bearing of the very short control periods. The first control indicated that the acid feeding had diminished the loss of calcium by 0.021 gram per day, while the second indicated that the acid administration had increased the loss of calcium by 0.393 gram per day.

No evidence was submitted as to the crucial point, the effect of the feeding of acid on the alkali reservc of the blood. As reported in the sixth paper of this series, later work in this laboratory has shown that the alkali reserve of the blood plasma of swine is susceptible of significant modification in accord with the potential acidity or alkalinity of the mineral supplements fed.

That the circulation of greatly increased amounts of acid-neutralization products did not appreciably affect nitrogen retention is as would be expected, but the evidence as to the effect of this factor on the reproductive activity of the sows was inconclusive, and the ultimate effects of the potential acidity of cereal rations and of the acidity or alkalinity of mineral supplements remain yet to be determined.

Our present study exhibits consistent effects of the mineral supplements fed, on the acid-base balance in the organism, as indicated by urinary ammonia and acidity, in accord with the prevailing views, the precipitated carbonate producing the least acid urine, and the precipitated bone flour, by virtue of its dicalcic salts, produced the most acid urine. No evidence is submitted as to the final significance, to the organism, of variations in the acid-base balance of the ration.

SUMMARY

1. This investigation was a study of the metabolism of growing swine on cereal rations as affected by the supplementary addition of (1) pulverized limestone, (2) precipitated bone flour, (3) raw rock phosphate floats, (4) "special" steamed bone flour, and (5) precipitated calcium carbonate. In one period the basal ration was fed without mineral supplement.

2. Prominent characteristics of the metabolism of swine on a ration of corn, linseed oilmeal and wheat middlings (with common salt provided) were loss of calcium, subnormal retention of magnesium and phosphorus, and high acidity and ammonia of the urine.

Potassium was supplied by this ration in superabundant amount, but sodium and chlorine were deficient except as provided in common salt.

3. The deficient intake of calcium constituted a prominent factor in the control of the retention of phosphorus, and, to a less marked extent, that of magnesium. Increased intake of calcium in the form of precipitated carbonate or of pulverized limestone (limestone floats) caused marked increase in calcium, magnesium and phosphorus retention.

4. One part of common salt to 450 parts of grain permitted retention of both sodium and chlorine by growing swine. The retention of sodium and potassium was usually about alike. The sodium requirement was more readily satisfied than the requirement for chlorine. All of the mineral supplements fed, but especially the precipitated bone flour, served to increase the retention of chlorine, as compared with the unsupplemented basal ration.

5. The magnesium content of all rations was sufficient When the magnesium balances were negative the loss was due to the limiting effect of other factors, especially to insufficient calcium intake. All of the mineral supplements fed had a favorable effect on the retention of magnesium. In certain instances this improvement in the magnesium retention was due entirely to the increased calcium intake.

6. In their efficiency to cause increased retention of calcium, as indicated by the percentage of the intake retained, four of the supplements, namely, pulverized limestone, precipitated bone flour, steamed bone flour and precipitated calcium carbonate differed but little, while the rock phosphate floats was decidedly the least efficient.

7. The retention of phosphorus was markedly increased by all of the calcium supplements, that is, by the carbonate as well as by the phosphate preparations. The relative efficiency to cause phosphorus retention was apparently determined by the solubility of the preparations, the most efficient being the precipitated calcium carbonate and precipitated bone flour, and the least efficient being the rock phosphate floats.

8. In comparison with the potentially acid basal ration, the carbonate preparations lowered urinary acidity and ammonia, while the precipitated bone flour (containing dicalcic phosphate) increased these products.

9. The mineral supplements did not affect the digestibility of the ration.

10. Of the sodium leaving the body about one-third was contained in the urine and two-thirds in the feces. A larger proportion of the potassium than of the sodium of the ration was eliminated in the urine; but a still larger proportion of the potassium was eliminated in the feces.

11. The ability of an organism to absorb mineral nutrients from the alimentary tract is limited, obviously, first of all by the solubility of these substances, and also, among other factors, by the rapidity with which they pass out of solution in the blood and lymph either by synthetic process or by excretion. Retention of absorbed mineral nutrients is controlled by nutritive requirements, and is not increased by the limitations of the capacities of elimination, since these limitations immediately react by restricting absorption.

12. The most efficient, probably because the most readily soluble, of the mineral supplements used were the precipitated carbonate and the precipitated bone flour. It may be, however, that other preparations will prove more practical, even though less efficient, in relation to amounts eaten, if pigs will take and can tolerate them in sufficient quantity.

13. The most urgent need of growing animals for a mineral supplement (aside from common salt) is satisfied by calcium carbonate. After balancing the phosphorus normally present in the ration, by the feeding of calcium carbonate, however, further strengthening of the skeleton requires the feeding of some form of calcium phosphate. With some waste of phosphorus the whole supplementary mineral requirement may be served by calcium phosphate. The phosphate is the more expensive, but is tolerated in greater quantity than is the carbonate, and, when fed separate from the ration, is more palatable.

TABLE I.—EXPERIMENT I: AVERAGE DAILY FOODS CONSUMED AND LIVE WEIGHTS OF PIGS (Grams)

Pig No. and days in period		Foods consumed							Weight of pigs	
		Total grain ration (plus salt)	Corn	Linseed oilmeal	Wheat middlings	Common salt	Distilled water	Mineral supplement	Weight at beginning of period	Weight at end of period
PERIOD I										
1	10	2152	1670.103	238.592	238.592	4.7344	2330	....	57,200	63,500
2	10	2088	1620.434	231.497	231.497	4.5936	2365	....	54,800	60,800
3	10	2144	1663.894	237.705	237.705	4.7168	2353	....	56,600	62,400
								Limestone floats		
4	10	1920	1490.054	212.870	212.870	4.2240	2297	14.038	50,000	55,800
5	10	1944	1508.680	215.531	215.531	4.2768	2382	14.038	51,800	57,800
PERIOD II								Prec. bone flour		
1	10	2152	1670.103	238.592	238.592	4.7344	2663	19.350	67,400	75,900
2	10	2310	1792.722	256.110	256.110	5.0820	2611	19.350	65,200	74,300
3	10	2372	1840.838	262.984	262.984	5.2184	2725	19.350	67,800	75,900
								Phosphate floats		
4	10	2120	1645.268	235.044	235.044	4.6640	2601	17.979	60,750	65,700
5	10	2196	1704.250	243.471	243.471	4.8312	2670	17.979	62,000	68,000
PERIOD III								Steamed bone flour		
1	10	2152	1670.103	238.592	238.592	4.7344	2870	16.932	81,900	87,800
2	10	1894	1470.032	210.010	210.010	4.1672	2450	13.884	79,800	83,800
3	10	2372	1840.838	262.984	262.984	5.2184	3070	16.932	81,600	90,300
								Calcium carbonate		
4	10	2120	1645.268	235.044	235.044	4.6640	2800	15.590	70,000	75,700
5	10	2196	1704.250	243.471	243.471	4.8312	3055	15.590	72,200	79,400

TABLE II.—EXPERIMENT I: COMPOSITION OF FOODS (Percent)

Food	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon
Corn	86.62	4.4373	1.7267	1.4046	8.7788	70.3709	1.3063	0.0518	0.3474	0.0125	0.1152	0.1285	0.0435	0.2641	0.0220
Linseed oilmeal	90.14	6.6613	6.5400	4.8802	30.5013	40.6240	5.8134	0.0712	1.3559	0.3523	0.5139	0.4165	0.0421	0.8645	0.2258
Wheat middlings	88.37	4.2840	3.7733	2.3526	14.7038	62.4566	3.1523	0.0680	0.8267	0.0720	0.2615	0.2015	0.0391	0.7425	0.0492
Common salt	99.63	......	......	......	......	......	......	38.3398	0.5356	0.4880	0.0163	0.3620	58.9256	......	......
Limestone floats (raw crushed stone)	99.89	......	......	......	......	......	99.07	0.0615	0.1174	35.2450	1.6705	0.0405	0.0182	0.0450	4.1300
Precipitated bone flour	94.65	0.2840	......	0.1169	0.7306	......	78.17	0.0521	0.0611	25.7025	0.4295	0.3130	2.0435	16.6355	0.4303
Phosphate floats (raw rock phosphate)	98.77	......	......	......	......	......	97.48	0.0333	0.5983	28.4000	0.4133	0.2750	0.0302	12.3050	5.6313
Steamed bone flour	96.66	3.1680	......	1.1160	6.9750	2.6670	83.85	0.5588	0.1174	30.3950	0.7545	0.3135	0.0578	14.0433	0.0873
Precipitated calcium carbonate	99.60	......	......	......	......	......	......	0.0214	0.0354	39.2700	0.5170	0.0930	0.0369	......	......

TABLE III.—EXPERIMENT I: CONSTITUENTS OF DAILY RATIONS (Grams)

Pig No.	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon
PERIOD I														
1	1872.554	100.222	53.445	40.715	254.471	1421.206	3.0124	11.0348	1.2443	3.7748	3.6377	3.7100	8.2448	1.0235
2	1816.835	97.240	51.855	39.505	246.903	1378.918	2.9226	10.7067	1.2073	3.6625	3.5296	3.5997	7.9998	0.9931
3	1865.589	99.734	53.245	40.564	253.525	1415.921	3.0012	10.9938	1.2395	3.7608	3.6242	3.6962	8.2143	1.0198
4	1670.675	89.417	47.683	36.325	227.037	1267.989	2.6964	9.8617	6.0578	3.6023	3.2512	3.3126	7.3624	1.4930
5	1691.565	90.535	48.279	36.780	229.875	1283.842	2.7299	9.9848	6.0717	3.6444	3.2919	3.3540	7.4543	1.5044
PERIOD II														
1	1872.554	100.222	53.445	40.738	254.612	1421.206	3.0225	11.0466	6.2177	3.8579	3.6983	4.1054	11.4638	1.1068
2	2010.036	107.580	57.369	43.728	273.295	1525.553	3.2437	11.8568	6.3090	4.1349	3.9654	4.3777	12.0693	1.1820
3	2063.989	110.468	58.908	44.900	280.628	1566.502	3.3304	12.1747	6.3448	4.2438	4.0702	4.4847	12.3069	1.2115
4	1844.710	98.732	52.650	40.110	250.686	1400.075	2.9736	10.9784	6.3318	3.7927	3.6331	3.6603	10.3347	2.0208
5	1910.841	102.271	54.537	41.548	259.674	1450.268	3.0801	11.3681	6.3756	3.9263	3.7616	3.7912	10.6258	2.0570
PERIOD III														
1	1872.554	100.758	53.445	40.904	255.652	1421.206	3.1070	11.0547	6.3908	3.9026	3.6908	3.7198	10.6226	1.2076
2	1648.229	88.656	47.042	35.993	224.954	1250.952	2.7291	9.7292	5.3152	3.4274	3.2455	3.2735	9.2069	1.0519
3	2063.989	111.004	58.908	45.066	281.668	1566.502	3.4149	12.1828	6.5179	4.2885	4.0627	4.0991	11.4657	1.3123
4	1844.710	98.732	52.650	40.110	250.686	1400.075	2.9709	10.8763	7.3470	3.7992	3.5982	3.6607	8.1224	1.0083
5	1910.841	102.271	54.537	41.548	259.674	1450.268	3.0774	11.2660	7.3918	3.9326	3.7267	3.7916	8.4135	1.0445

TABLE IV.—EXPERIMENT I: CONSTITUENTS OF AVERAGE DAILY URINE

Pig No.	Nitrogen	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Acidity	Ammonia
PERIOD I	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*C. C. N/10*	*Grams*
1	16.3882	0.4840	4.0903	0.1139	0.4423	1.5696	3.0572	2.0805	882	2.682
2	16.7205	0.4733	3.4260	0.1279	0.3384	1.5400	3.3943	2.2336	876	3.025
3	16.9895	0.4689	4.2385	0.1026	0.4079	1.6558	3.4060	2.3811	888	3.157
4	15.6294	0.4129	3.3194	0.1467	0.5124	1.4084	2.4418	0.5962	261	1.972
5	16.1096	0.4478	3.0222	0.1646	0.4661	1.4421	2.7009	0.5309	292	2.092
PERIOD II										
1	17.9922	0.4254	3.4763	0.1537	0.3526	1.5173	2.5728	3.0630	1,134	2.987
2	19.0550	0.6003	3.1384	0.1288	0.4248	1.6745	2.9766	3.4979	1,247	3.535
3	18.9831	0.6368	3.4206	0.1167	0.4576	1.7732	2.9920	3.6380	1,161	4.100
4	16.8454	0.5148	2.8076	0.1714	0.5185	1.4475	3.1044	2.6661	1,077	3.161
5	17.0885	0.4456	2.9375	0.2165	0.5621	1.5929	3.0325	2.6891	1,043	3.297
PERIOD III										
1	21.2616	0.2203	4.9788	0.1987	0.2564	1.6873	3.3319	2.2043	919	2.639
2	20.0870	0.4367	4.1958	0.1565	0.2865	1.5543	2.9967	2.3879	939	2.513
3	23.8927	0.5074	3.4887	0.1613	0.3206	1.9198	2.6805	2.7458	1,055	3.698
4	17.2320	0.4643	4.0513	0.1507	0.5388	1.5001	2.7308	0.1302	194	1.608
5	19.6846	0.4087	4.0541	0.2466	0.5312	1.6948	3.0380	0.1581	227	1.867

TABLE V.—EXPERIMENT I: CONSTITUENTS OF AVERAGE DAILY FECES (Grams)

Pig No.	Total weight	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus
PERIOD I														
1	10,812	347.7139	43.2967	41.9852	12.4598	77.8734	152.4665	0.8282	5.1303	1.4477	3.4242	1.1558	0.1816	5,2114
2	10,674	361.8486	42.0193	38.2183	12.3125	76.9531	171.6155	0.8187	5.6658	1.4794	3.4851	1.1507	0.3021	5.1086
3	10,895	347.1147	38.4615	41.6941	13.5360	84.5997	150.0808	0.8956	5.0814	1.5406	3.5529	1.1342	0.1928	5.3527
4	10,213	316.2966	29.5258	36.8802	10.8288	67.6805	149.0516	0.7568	5.0432	2.8658	3.0282	1.0387	0.2502	4.6153
5	9,927	311.3107	28.5113	33.6883	10.9465	68.4159	146.3031	0.6959	5.5244	2.9027	3.0982	1.0959	0.2710	4.8613
PERIOD II														
1	10,022	317.7976	35.9018	38.1267	10.9180	68 2378	141.1138	0.8429	6.4963	2.3712	3.4095	1.1315	0.2375	5.8919
2	11,064	371.4185	50.5215	42.5887	12.8154	80.0967	161.1295	1.0456	6.5665	2.7007	3.6478	1.2635	0.3806	6.0498
3	12,068	370.3669	33.5575	47.0097	13.0600	81.6255	170.0611	0.7844	7.3373	2.8203	3.6083	1.3287	0.3524	6.1824
4	11,956	369.5600	31.6942	39.1535	12.5179	78.2377	178.3094	1.2375	6.3462	3.9849	3.2437	1.2865	0.3766	6.0701
5	12,106	378.7967	30.6923	38.5758	13.7851	86.1572	179.2596	1.4503	6.6983	3.9284	3.3534	1.4067	0.3753	6.2636
PERIOD III														
1	9 525	321.8498	35.1787	40.6879	11.3586	70.9908	138.1192	0.8649	3.7224	3.0461	3.6547	1.1516	0.1886	6.4237
2	7,704	291.7505	36.0763	36.9130	9.4998	59.3740	127.6198	0.8290	4.4853	2.5554	3.1887	0.9746	0.2627	5.0407
3	11,446	346.9283	38.8008	44.7321	11.0420	69.0125	155.1379	0.9775	7.2533	2.9897	3.8676	1.0714	0.2759	6.1591
4	10,061	338.5527	39.4955	40.6223	12.5109	78.1931	145.0394	0.7868	4.6442	3.0354	3.1682	1.1681	0.2646	5.4511
5	9,588	322.2527	32.6308	42.1978	12.6763	79.2266	132.7928	0.7680	5.9369	2.7911	3.2551	1.1180	0.2368	5.4757

TABLE VI.—PERIOD I, EXPERIMENT I: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Food Urine Feces Balance
1	Corn 1670.103; linseed oilmeal 238.592; wheat middlings 238.592; common salt 4.7344	Basal ration	3.012 0.484 0.828 +1.700	11.035 4.090 5.130 +1.815	1.244 0.114 1.448 —0.318	3.775 0.442 3.424 —0.091	3.638 1.570 1 156 +0.912	3.793 3.057 0.182 +0.554	8.245 2.081 5.211 +0.953	40.715 16.388 12.460 +11.867
2	Corn 1620.434; linseed oilmeal 231.497; wheat middlings 231.497; common salt 4.5936	Basal ration	2.923 0.473 0.819 +1.631	10.707 3.426 5.666 +1.615	1.207 0.128 1.479 —0.400	3.663 0.338 3.485 —0.160	3.530 1.540 1.151 +0.839	3.681 3.394 0.302 —0.015	8.000 2.234 5.109 +0.657	39.505 16.721 12.313 +10.471
3	Corn 1663.894; linseed oilmeal 237.705; wheat middlings 237.705; common salt 4.7168	Basal ration	3 001 0.469 0.896 +1.636	10.994 4.239 5.081 +1.674	1.240 0.103 1.541 —0.404	3.761 0.408 3.553 —0.200	3.624 1.656 1.134 +0.834	3.779 3.406 0.193 +0.180	8.214 2.381 5.353 +0.480	40.564 16.990 13.536 +10.038
4	Corn 1490.054; linseed oilmeal 212.870; wheat middlings 212.870; common salt 4.2240; limestone floats 14.038	Basal ration plus limestone floats	2.696 0.413 0.757 +1.526	9.862 3.319 5.043 +1.500	6.058 0.147 2.866 +3.045	3.602 0.512 3.028 +0.062	3.251 1.408 1.039 +0.804	3.387 2.442 0.250 +0.695	7.362 0.596 4.615 +2.151	36.325 15.629 10.829 + 9.867
5	Corn 1508.680; linseed oilmeal 215.531; wheat middlings 215.531; common salt 4.2768; limestone floats 14.038	Basal ration plus limestone floats	2.730 0.448 0.696 +1 586	9.985 3.022 5.524 +1.439	6 072 0.165 2.903 +3.004	3.644 0.466 3.098 +0.080	3.292 1.442 1.096 +0.754	3.429 2.701 0.271 +0.457	7.454 0.531 4.861 +2.062	36.780 16.110 10.947 + 9.723

TABLE VII.—PERIOD II, EXPERIMENT I: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Food Urine Feces Balance
1	Corn 1670.103; linseed oilmeal 238.592; wheat middlings 238.592; common salt 4.7344; precipitated bone flour 19.350	Basal ration plus precipitated bone flour	3.023 0.425 0.843 +1.755	11.047 3.476 6.496 +1.075	6.218 0.154 2.371 +3.693	3.858 0.353 3.410 +0.095	3.698 1.517 1.132 +1.049	4.189 2.573 0.238 +1.378	11.464 3.063 5.892 +2.509	40.738 17.992 10.918 +11.828
2	Corn 1792.722; linseed oilmeal 256.110; wheat middlings 256.110; common salt 5.0820; precipitated bone flour 19.350	Basal ration plus precipitated bone flour	3.244 0.600 1.046 +1.598	11.857 3.138 6.567 +2.152	6.309 0.129 2.701 +3.479	4.135 0.425 3.648 +0.062	3.965 1.675 1.264 +1.026	4.467 2.977 0.381 +1.109	12.069 3.498 6.050 +2.521	43.728 19.055 12.815 +11.858
3	Corn 1840.838; linseed oilmeal 262.984; wheat middlings 262.984; common salt 5.2184; precipitated bone flour 19.350	Basal ration plus precipitated bone flour	3.330 0.637 0.784 +1.909	12.175 3.421 7.337 +1.417	6.345 0.117 2.820 +3.408	4.244 0.458 3.608 +0.178	4.070 1.773 1.329 +0.968	4.577 2.992 0.352 +1.233	12.307 3.638 6.182 +2.487	44 900 18.983 13.060 +12.857
4	Corn 1645.268; linseed oilmeal 235.044; wheat middlings 235.044; common salt 4.6640; phosphate floats 17.979	Basal ration plus phosphate floats	2.974 0.515 1.238 +1.221	10.978 2.808 6.346 +1.824	6.332 0.171 3.985 +2.176	3.793 0.519 3.244 +0.030	3.633 1.448 1.287 +0.898	3.742 3.104 0.377 +0.261	10.335 2.666 6.070 +1.599	40.110 16.845 12.518 +10.747
5	Corn 1704.250; linseed oilmeal 243.471; wheat middlings 243.471; common salt 4.8312; phosphate floats 17.979	Basal ration plus phosphate floats	3.080 0.446 1.450 +1.184	11.368 2.938 6.698 +1.732	6.376 0.217 3.928 +2.231	3.926 0.562 3.353 +0.011	3.762 1.593 1.407 +0.762	3.876 3.033 0.375 +0.468	10.626 2.689 6.264 +1.673	41.548 17.089 13.785 +10.674

TABLE VIII.—PERIOD III, EXPERIMENT I: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Food Urine Feces Balance
1	Corn 1670.103; linseed oilmeal 238.592; wheat middlings 238.592; common salt 4.7344; steamed bone flour 16.932	Basal ration plus steamed bone flour	3.107 0.220 0.865 +2.022	11.055 4.979 3.722 +2.354	6.391 0.199 3.046 +3.146	3.903 0.256 3.655 −0.008	3.691 1.687 1.152 +0.852	3.803 3.332 0.189 +0.282	10.623 2.204 6.424 +1.995	40.904 21.262 11.359 +8.283
2	Corn 1470.032; linseed oilmeal 210.010; wheat middlings 210.010: common salt 4.1672; steamed bone flour 13.884	Basal ration plus steamed bone flour	2.729 0.437 0.829 +1.463	9.729 4.196 4.485 +1.048	5.315 0.157 2.555 +2.603	3.427 0.287 3.189 −0.049	3.246 1.554 0.975 +0.717	3.347 2.997 0.263 +0.087	9.207 2.388 5.041 +1.778	35.993 20.087 9.500 +6.406
3	Corn 1840.838; linseed oilmeal 262.984; wheat middlings 262.984; common salt 5.2184; steamed bone flour 16.932	Basal ration plus steamed bone flour	3.415 0.507 0.978 +1.930	12.183 3.489 7.253 +1.441	6.518 0.161 2.990 +3.367	4.289 0.321 3.868 +0.100	4.063 1.920 1.071 +1.072	4.191 2.681 0.276 +1.234	11.466 2.746 6.159 +2.561	45.066 23.893 11.042 +10.131
4	Corn 1645.268; linseed oilmeal 235.044;wheat middlings 235.044; common salt 4.6640; calcium carbonate 15.590	Basal ration plus calcium carbonate	2.971 0.464 0.787 +1.720	10.876 4.051 4.644 +2.181	7.347 0.151 3.035 +4.161	3.799 0.539 3.168 +0.092	3.598 1.500 1.168 +0.930	3.743 2.731 0.265 +0.747	8.122 0.130 5.451 +2.541	40.110 17.232 12.511 +10.367
5	Corn 1704.250; linseed oilmeal 243.471; wheat middlings 243.471; common salt 4.8312; calcium carbonate 15.590	Basal ration plus calcium carbonate	3.077 0.409 0.768 +1.900	11.266 4.054 5.937 +1.275	7.392 0.247 2.791 +4.354	3.933 0.531 3.255 +0.147	3.727 1.695 1.118 +0.914	3.877 3.038 0.237 +0.602	8.414 0.158 5.476 +2.780	41.548 19.685 12.676 +9.187

TABLE IX.—EXPERIMENT I: INTAKE AND RETENTION OF MINERAL ELEMENTS AND NITROGEN PER KILOGRAM OF LIVE WEIGHT. Intake and Retention in Grams; Percent Retention Based on Intake; Data are Averages of Results from All Pigs on Same Treatment

Period No. Average live weight Kilos	Distinguishing features of rations	Sodium Intake Retention Percent Ret.	Potassium Intake Retention Percent Ret.	Calcium Intake Retention Percent Ret.	Magnesium Intake Retention Percent Ret.	Sulphur Intake Retention Percent Ret.	Chlorine Intake Retention Percent Ret.	Phosphorus Intake Retention Percent Ret.	Nitrogen Intake Retention Percent Ret.
1 59.217	Basal ration	0.050 +0.028 +55.6%	0.184 +0.029 +15.6%	0.021 −0.006 −30.4%	0.063 −0.003 −4.02%	0.061 +0.015 +24.0%	0.063 +0.004 +6.4%	0.138 +0.012 + 8.5%	0.680 +0.182 +26.8%
1 53.850	Limestone floats	0.050 +0.029 +57.4%	0.184 +0.027 +14.8%	0.113 +0.056 +49.9%	0.067 +0.001 +1.96%	0.061 +0.014 +23.8%	0.063 +0.011 +16.9%	0.138 +0.039 +28.4%	0.679 +0.182 +26.8%
2 71.083	Precip. bone flour	0.045 +0.025 +54.8%	0.164 +0.022 +13.2%	0.089 +0.050 +56.1%	0.067 +0.002 +2.7%	0.055 +0.014 +25.9%	0.062 +0.017 +28.1%	0.168 +0.035 +21.0%	0.607 +0.171 +28.2%
2 64.113	Phosphate floats	0.047 +0.019 +39.7%	0.174 +0.028 +15.9%	0.099 +0.034 +34.7%	0.060 +0.0003 +0 5%	0.058 +0.013 +22.4%	0.059 +0.006 + 9.6%	0.163 +0.026 +15.6%	0.637 +0.167 +26.2%
3 85.400	Steamed bone flour	0.038 +0.023 +60.6%	0.136 +0.022 +16.3%	0.076 +0.038 +50.5%	0.048 +0.0005 +1.1%	0.045 +0.011 +24.8%	0.047 +0.009 +19.0%	0.129 +0.027 +20.6%	0.503 +0.108 +21.4%
3 74.325	Calcium carbonate	0.041 +0.024 +59.9%	0.149 +0.023 +15.6%	0.099 +0.057 +57.8%	0.052 +0.002 +3.1%	0.049 +0.012 +25.2%	0.051 +0.009 +17.7%	0.111 +0.036 +32.2%	0.549 +0.132 +23.9%

Note: Pig 2, Period III, was not included in these averages.

TABLE X.—PERIOD I, EXPERIMENT I: AVERAGE DAILY FEED (Pounds) AND BALANCE DATA (Grams)

Pig No.	Rations (Pounds)	Distinguishing features of rations	Gain or loss to the body (Grams)							
			Sodium Intake Balance	Potassium Intake Balance	Calcium Intake Balance	Magnesium Intake Balance	Sulphur Intake Balance	Chlorine Intake Balance	Phosphorus Intake Balance	Nitrogen Intake Balance
1	Corn 3.6819; linseed oilmeal 0.5260; wheat middlings 0.5260; common salt 0.0104	Basal ration	3.012 +1.700	11.035 +1.814	1.244 —0.318	3.775 —0.091	3.638 +0.912	3.793 +0.554	8.245 +0.953	40.715 +11.867
2	Corn 3.5724; linseed oilmeal 0.5104; wheat middlings 0.5104; common salt 0.0101	Basal ration	2.923 +1.631	10.707 +1.615	1.207 —0.400	3.663 —.0160	3.530 +0.839	3.681 —0.015	8.000 +0.657	39.505 +10.471
3	Corn 3.6682; linseed oilmeal 0.5240; wheat middlings 0.5240; common salt 0.0104	Basal ration	3.001 +1.637	10.994 +1.674	1.240 —0.404	3.761 —0.200	3.624 +0.834	3.779 +0.180	8.214 +0.480	40.564 +10.038
4	Corn 3.2850; linseed oilmeal 0.4693; wheat middlings 0.4693; common salt 0.0093; limestone floats 0.0309	Basal ration plus limestone floats	2.696 +1.527	9.862 +1.499	6.058 +3.045	3.602 —0.062	3.251 +0.804	3.387 +0.695	7.362 +2.151	36.325 +9.867
5	Corn 3.3260; linseed oilmeal 0.4752; wheat middlings 0.4752; common salt 0.0094; limestone floats 0.0309	Basal ration plus limestone floats	2.730 +1.586	9.985 +1.438	6.072 +3.004	3.644 +0.080	3.292 +0.754	3.429 +0.457	7.454 +2.062	36.780 +9.723

TABLE XI.—PERIOD II, EXPERIMENT I: AVERAGE DAILY FEED (Pounds) AND BALANCE DATA (Grams)

Pig No.	Rations (Pounds)	Distinguishing features of rations	Gain or loss to the body (Grams)															
			Sodium		Potassium		Calcium		Magnesium		Sulphur		Chlorine		Phosphorus		Nitrogen	
			Intake	Balance	Intake	Balance	Intake	Balance	Intake	Balance	Intake	Balance	Intake	Balance	Intake	Balance	Intake	Balance
1	Corn 3.6819; linseed oilmeal 0.5260; wheat middlings 0.5260; common salt 0.01044; precipitated bone flour 0.0427	Basal ration plus precipitated bone flour	3.023	+1.754	11.047	+1.074	6.218	+3.693	3.858	+0.095	3.698	+1.049	4.189	+1.378	11.464	+2.509	40.738	+11.828
2	Corn 3.9522; linseed oilmeal 0.5646; wheat middlings 0.5646; common salt 0.0112; precipitated bone flour 0.0427	Basal ration plus precipitated bone flour	3.244	+1.598	11.857	+2.152	6.309	+3.479	4.135	+0.062	3.965	+1.026	4.467	+1.109	12.069	+2.521	43.728	+11.858
3	Corn 4.0583; linseed oilmeal 0.5798; wheat middlings 0.5798; common salt 0.0115; precipitated bone flour 0.0427	Basal ration plus precipitated bone flour	3.330	+1.909	12.175	+1.417	6.345	+3.408	4.244	+0.178	4.070	+0.968	4.577	+1.233	12.307	+2.487	44.900	+12.857
4	Corn 3.6271; linseed oilmeal 0.5182; wheat middlings 0.5182; common salt 0.0103; phosphate floats 0.0396	Basal ration plus phosphate floats	2.974	+1.221	10.978	+1.825	6.332	+2.176	3.793	+0.030	3.633	+0.898	3.742	+0.261	10.335	+1.599	40.110	+10.747
5	Corn 3.7572; linseed oilmeal 0.5368; wheat middlings 0.5368; common sa t 0,0107; phosphate floats 0.0396	Basal ration plus phosphate floats	3.080	+1.184	11.368	+1.732	6.376	+2.231	3.926	+0.011	3.762	+0.762	3.876	+0.468	10.626	+1.673	41.548	+10.674

TABLE XII.—PERIOD III, EXPERIMENT I: AVERAGE DAILY FEED (Pounds) AND BALANCE DATA (Grams)

Pig No.	Rations (Pounds)	Distinguishing features of rations	Gain or loss to the body (Grams)							
			Sodium Intake Balance	Potassium Intake Balance	Calcium Intake Balance	Magnesium Intake Balance	Sulphur Intake Balance	Chlorine Intake Balance	Phosphorus Intake Balance	Nitrogen Intake Balance
1	Corn 3.6819; linseed oilmeal 0.5260; wheat middlings 0.5260; common salt 0.01044; steamed bone flour 0.0373	Basal ration plus steamed bone flour	3.107 +2.022	11.055 +2.354	6.391 +3.146	3.903 —0.008	3.691 +0.852	3.803 +0.282	10.623 +1.995	40.904 +8.283
2	Corn 3.2408; linseed oilmeal 0.4629; wheat middlings 0.4629; common salt 0.00919; steamed bone flour 0.0306	Basal ration plus steamed bone flour	2.729 +1.463	9.729 +1.048	5.315 +2.603	3.427 —0.049	3.246 +0.717	3.347 +0.087	9.207 +1.778	35.993 +6.406
3	Corn 4.0583; linseed oilmeal 0.5798; wheat middlings 0.5798; common salt 0.0115; steamed bone flour 0.0373	Basal ration plus steamed bone flour	3.415 +1.930	12.183 +1.441	6.518 +3.367	4.289 +0.100	4.063 +1.072	4.191 +1.234	11.466 +2.561	45.066 +10.131
4	Corn 3.6271; linseed oilmeal 0.5182; wheat middlings 0.5182; common salt 0.0103; calcium carbonate 0.0344	Basal ration plus calcium carbonate	2.971 +1.720	10.876 +2.181	7.347 +4.161	3.799 +0.092	3.598 +0.930	3.743 +0.747	8.122 +2.541	40.110 +10.367
5	Corn 3.7572; linseed oilmeal 0.5368; wheat middlings 0.5368; common salt 0.0107; calcium carbonate 0.0344	Basal ration plus calcium carbonate	3.077 +1.901	11.266 +1.275	7.392 +4.354	3.933 +0.147	3.727 +0.914	3.877 +0.602	8.414 +2.780	41.548 +9.187

TABLE XIII.—EXPERIMENT 1: AMMONIA AND ACIDITY OF URINE AS AFFECTED BY MINERAL SUPPLEMENTS
Individual Daily Data—Ammonia in Grams; Acidity in Cubic Centimeters of Tenth-Normal Acid

Date	Pig 1		Pig 2		Pig 3		Pig 4		Pig 5	
	Ammonia Grams	Acidity C. C.	Ammonia Grams	Acidity C. C.	Ammonia Grams	Acidity C. C.	Ammonia Grams	Acidity C. C.	Ammonia Grams	Acidity C. C.
Period I	Basal ration		Basal ration		Basal ration		Limestone Floats		Limestone Floats	
November 5	1.679	658	2,723	729	2.522	715	1.653	198	1.963	290
November 6	2.917	1,006	2,683	789	3.438	911	1.513	159	1.916	260
November 7	2.753	814	3,384	789	3.384	785	1.813	183	2.097	164
November 8	2.665	820	3,531	847	3.511	763	1.620	143	2.255	264
November 9	2.184	806	3,211	1,128	3.216	954	2.239	333	1.824	261
November 10	2.952	936	2,745	889	3.091	1,083	2.133	322	1.902	382
November 11	3.179	957	2,623	857	2.486	1,006	2.251	391	2.083	353
November 12	3.123	1,061	3,298	978	3.606	887	2.555	355	2.698	360
Average	2.682	882	3.025	876	3.157	888	1.972	261	2.092	292
Period II	Precip. Bone Flour		Precip. Bone Flour		Precip. Bone Flour		Phosphate Floats		Phosphate Floats	
November 21	2.651	747	3.336	864	3.661	867	2.803	665	2.726	610
November 22	2.740	1,141	3.348	1,324	3.859	1,237	3.120	1,081	3.174	1,121
November 23	3.320	1,304	3.557	1,282	4.465	1,042	3.263	954	3.483	964
November 24	3.219	1,088	3.636	1,143	4.264	1,126	3.182	1,048	3.714	979
November 25	3.117	1,188	3.716	1,355	3.752	905	3.573	1,007	3.329	1,009
November 27	2.907	1,116	3.592	1,272	4.340	1,568	3.039	1,369	3.409	1,460
November 28	....	1,163	....	1,307	....	1,230	....	1,048	....	983
November 29	2.952	1,327	3.557	1,429	4.358	1,309	3.147	1,442	3.244	1,216
Average	2.987	1,134	3.535	1,247	4,100	1,161	3.161	1,077	3.297	1,043
Period III	Steamed Bone Flour		Steamed Bone Flour		Steamed Bone Flour		Calc. Carbonate		Calc. Carbonate	
December 9	2.633	941	2.371	893	3.341	1,046	1.721	199	1.814	259
December 10	2.029	813	2.818	1,155	3.486	1,091	1.528	228	1.408	199
December 11	2.830	1,009	2.314	966	3.565	1,130	1.127	165	1.249	184
December 12	2.468	922	2.640	1,042	2.123	578	1.139	141	1.255	177
December 13	2.297	720	2.016	751	4.431	1,184	1.563	201	2.302	309
December 14	3.400	1,135	2.111	773	4.544	1,144	1.928	211	2.640	208
December 15	2.881	897	2.526	818	3.932	1,082	2.101	186	2.226	271
December 18	2.571	918	3.311	1,113	4.163	1,186	1.755	221	2.043	211
Average	2.639	919	2.513	939	3.698	1,055	1.608	194	1.867	227

TABLE XIV.—EXPERIMENT I: UTILIZATION AND ELIMINATION OF NITROGEN

Pig No.	Distinguishing features of rations	Nitrogen of rations per day	Nitrogen in urine per day	Ammonia nitrogen in urine per day	Ammonia nitrogen in urinary nitrogen	Nitrogen of food in urine	Utilization of nitrogen	Nitrogen of food in feces
PERIOD I		*Grams*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1	Basal ration	40.715	16.388	2.206	13.46	40.25	29.15	30.60
2		39.505	16.721	2.489	14.89	42.33	26.50	31.17
3		40.564	16.990	2.597	15.29	41.88	24.75	33 37
4	Basal ration plus limestone floats	36.325	15.629	1.622	10.38	43.03	27.16	29.81
5		36.780	16.110	1.721	10.68	43.80	26.44	29.76
PERIOD II								
1	Basal ration plus precipitated bone flour	40.738	17.992	2.457	13.66	44.17	29.03	26.80
2		43.728	19.055	2.908	15.26	43.58	27.11	29.31
3		44.900	18.983	3.373	17.77	42.28	28.63	29.09
4	Basal ration plus phosphate floats	40.110	16.845	2.600	15.43	42.00	26.79	31.21
5		41.548	17.089	2.712	15.87	41.13	25.69	33.18
PERIOD III								
1	Basal ration plus steamed bone flour	40.904	21.262	2.171	10.21	51.98	20.25	27.77
2		35.993	20.087	2.067	10.29	55.81	17.80	26.39
3 *		45.066	23.893	3.042	12.73	53.02	22.48	24.50
4	Basal ration plus calcium carbonate	40.110	17.232	1.323	7.68	42.96	25.85	31.19
5		41.548	19.685	1.536	7.80	47.38	22.11	30.51

TABLE XV.—EXPERIMENT I: DISTRIBUTION OF OUTGO OF ELEMENTS BETWEEN URINE AND FECES (Percent)

Pig No.	Distinguishing features of rations	Sodium Urine	Sodium Feces	Potassium Urine	Potassium Feces	Calcium Urine	Calcium Feces	Magnesium Urine	Magnesium Feces	Sulphur Urine	Sulphur Feces	Chlorine Urine	Chlorine Feces	Phosphorus Urine	Phosphorus Feces	Nitrogen Urine	Nitrogen Feces
PERIOD I																	
1	Basal ration	36.88	63.12	44.36	55.64	7.29	92.71	11.43	88.57	57.59	42.41	94.38	5.62	28.54	71.46	56.81	43.19
2	Basal ration	36.63	63.37	37.68	62.32	7.97	92.03	8.84	91.16	57.23	42.77	91.83	8.17	30.42	69.58	57.59	42.41
3	Basal ration	34.36	65.64	45.48	54.52	6.27	93.73	10.30	89.70	59.35	40.65	94.64	5.36	30.79	69.21	55.66	44 34
4	Basal ration plus limestone floats	35.30	64.70	39.69	60.31	4.88	95.12	14.46	85.54	57.54	42.46	90.71	9.29	11.44	88.56	59.07	40.93
5	Basal ration plus limestone floats	39.15	60.85	35.36	64.64	5.38	94.62	13.08	86.92	56.82	43.18	90.88	9.12	9.85	90.15	59.54	40.46
PERIOD II																	
1	Basal ration plus precipitated bone flour	33.54	66.46	34.86	65.14	6.10	93.90	9.38	90.62	57.27	42.73	91.53	8.47	34.20	65.80	62.23	37.77
2	Basal ration plus precipitated bone flour	36.47	63.53	32.34	67.66	4.56	95.44	10.43	89.57	56.99	43.01	88.65	11.35	36 64	63.36	59.79	40.21
3	Basal ration plus precipitated bone flour	44.81	55.19	31.80	68.20	3.98	96.02	11.26	88.74	57 16	42.84	89.47	10.53	37.05	62.95	59.24	40.76
4	Basal ration plus phosphate floats	29.38	70.62	30.67	69.33	4.11	95.89	13.79	86.21	52.94	47.06	89.17	10.83	30.52	69.48	57.37	42.63
5	Basal ration plus phosphate floats	23.50	76.50	30.49	69.51	5.24	94.76	14.36	85.64	53.10	46.90	89.00	11.00	30.03	69.97	55.35	44.65
PERIOD III																	
1	Basal ration plus steamed bone flour	20.30	79.70	57.22	42.78	6.13	93.87	6.55	93.45	59.42	40.58	94.63	5.37	25.54	74.46	65.18	34.82
2	Basal ration plus steamed bone flour	34.50	65.50	48.33	51.67	5.79	94.21	8.26	91.74	61.45	38.55	91.93	8.07	32.14	67.86	67.89	32.11
3	Basal ration plus steamed bone flour	34.17	65.83	32.48	67.52	5.11	94.89	7.66	92.34	64.19	35.81	90.67	9.33	30.84	69.16	68.39	31.61
4	Basal ration plus calcium carbonate	37.11	62.89	46.59	53.41	4.74	95.26	14.54	85.46	56.22	43.78	91.15	8.85	2.33	97.67	57.94	42.06
5	Basal ration plus calcium carbonate	34.73	65.27	40.58	59.42	8.13	91.87	14.03	85.97	60.26	39.74	92.76	7.24	2.80	97.20	60.83	39.17

TABLE XVI.—EXPERIMENT I: COEFFICIENTS OF DIGESTIBILITY OF RATIONS

Pig No.	Distinguishing features of rations	Protein	Nitrogen-free extract	Ether extract	Crude fiber
PERIOD I					
1		69.40	89.27	56.80	21.44
2	Basal ration	68.83	87.55	56.79	26.30
3		66.63	89.40	61.44	21.69
4	Basal ration plus limestone floats	70.19	88.25	66.98	22.66
5		70.24	88.60	68.51	30.22
PERIOD II					
1		73.20	90.07	64.18	28.66
2	Basal ration plus precipitated bone flour	70.69	89.44	53.04	25.76
3		70.91	89.14	69.62	20.20
4	Basal ration plus phosphate floats	68.79	87.26	67.90	25.63
5		66.82	87.64	69.99	29.27
PERIOD III					
1		72.23	90.28	65.09	23.87
2	Basal ration plus steamed bone flour	73.61	89.80	59.31	21.53
3		75.50	90.10	65.05	24.06
4	Basal ration plus calcium carbonate	68.81	89.64	60.00	22.85
5		69.49	90 84	68.09	22.63

2. THE UTILIZATION OF CALCIUM COMPOUNDS BY SWINE—II

This experiment, conducted between July 29 and October 26, 1918, was a continuation of the preceding one, by the same general method of operation, and with the same basal ration, but with certain changes in the mineral supplements which were compared.

Four purebred Poland China barrows were the subjects of this investigation. They were taken through five 10-day collection periods, separated by the usual 7-day intermediate periods, during which they were fed the rations of the collection periods to follow. Throughout this investigation, involving the use of five different rations, the four pigs were always given the same treatment, thus providing four observations on each point of interest.

The live weights of these pigs at the beginning of the first collection period were, in the order of their numbers, 48.0, 59.1, 50.3 and 49.1 kilograms, respectively. The final live weights, at the end of Period V, were 102.9, 116.0, 104.6 and 99.5 kilograms, respectively. This experiment, therefore, covered the period of most active growth, beginning when the subjects weighed about 113 pounds and ending when they had reached an average weight of 232 pounds. They were of the "big type," and were not in finished market condition at the end of this study.

The experiment progressed from the beginning to end in a successful manner, without incident or disqualifying circumstance.

The rations used were the following:

1. Basal ration, plus precipitated bone flour.
2. Same, plus a mixture of precipitated bone flour and steamed bone flour, half and half.
3. Same, plus precipitated bone flour and pulverized limestone, 90 parts of the former and 10 parts of the latter.
4. Same, plus "special" steamed bone flour.
5. Basal ration alone.

The basal ration was composed, as in the preceding study, of cornmeal 350 parts, wheat middlings 50 parts, linseed oilmeal 50 parts, and salt 1 part, the only difference being that in this experiment the salt used was chemically pure sodium chloride, instead of common salt.

The precipitated bone flour and the "special" steamed bone flour were used as in the previous experiment, and for two purposes; first, to confirm observations made in the first experiment, and second, as a basis for comparison with mixed mineral supplements in the composition of which these two bone preparations were used. In these mixtures we attempted to improve upon the two bone preparations by making a half-and-half mixture of the two, and a mixture of 90 percent of precipitated bone flour with 10 percent of pulverized limestone. In the first of these mixtures we employed the precipitated bone flour to add to the solubility of the steamed bone flour; and in the second we used the pulverized limestone to satisfy the deficiency of calcium as compared with phosphorus which is characteristic of the precipitated bone flour. We regret to say that our plan to supplement the precipitated bone flour with calcium carbonate miscarried, in a measure, and through no act of our own, in that the preparation used was found, after the feeding had been completed, to be a dolomitic (magnesian) limestone preparation, instead of calcium limestone as intended. Calculation indicates that this limestone contained about 13 percent of calcium and 14 percent of magnesium.

Each of the mineral supplements was fed in exactly the amount necessary to provide 5 grams of the element calcium per pig per day.

METHODS OF EXPERIMENTATION

Chemical analyses were made, in triplicate, as usual, by the methods indicated on pages 6 to 8, except as specified below:

Moisture: Feeds and feces were dried at 65 degrees Centigrade in the hot air oven, for 6 hours; they were then weighed, dried 6 hours more, weighed again, and placed in vacuum over sulphuric acid for drying to constant weight. Mineral supplements were dried to constant weight in the hot air oven at 105 degrees Centigrade.

Nitrogen: On feeds and feces by the Gunning method, using potassium sulphate and crystallized copper sulphate, and also potassium permanganate in the case of those digested solutions which did not clear up readily. The troublesome sulphids occasionally coming over in the distillates were thus avoided. The carrying over of alkali was avoided by the use of the Davisson distilling head and receiver.*

Sodium: Official methods I and II** combined and modified, weighing as the combined sulphates, determining potassium by the platinic chloride method, and sodium by difference.

Sulphur: On feeds and feces the modified Benedict† method was used; on urine the Benedict method was used.‡

Chlorine: The official Volhard method, after ashing in the presence of sodium carbonate, with original modifications.§

*Journ. Ind. and Eng. Chem. 11 (1919) 465.
**Rpt. Comm. on Editing Tentative and Official Methods of Anal., Assn. Offic. Agr. Chem. 1 (1915), 32.
†Journ. Am. Chem. Soc., 41 (1919), 1494.
‡Journ. Biol. Chem. 6 (1910), 363.
§Journ. Biol. Chem. 41 (1920), 205.

FEEDS CONSUMED AND GAINS IN WEIGHT

As indicating the general plane of metabolism of the subjects of this experiment,—the average daily feed consumption during the five periods was 0.751, 2.226, 2.792, 2.792 and 3.005 kiligrams, respectively; while the average daily gains in weight of the pigs during the five periods were 0.455, 0.698, 0.908, 0.805 and 0.708 kilogram, respectively, the general average being 0.705 kilogram or 1.57 pounds. These increases in weight were fully up to the average for pigs fed in the usual way, and were exceptional for pigs confined in metabolism crates. The results, then, may be considered as applying to pigs reared in a practical manner and making normal growth.

The individual data of feed consumption and gain in weight are set forth in Table I, page 45.

COMPOSITION OF FEEDS

The chemical analyses of the feeds and mineral supplements used showed that these were typical and in good condition. The mineral supplements (aside from the sodium chloride) were crude commercial preparations, and the steamed bone flour which was fed alone in Period IV was the same as that fed in the previous experiment but of a different lot from the steamed bone flour which entered into the composition of the mixture fed in Period II. On this account the composition of this half-and-half mixture is not a mathematical mean between the compositions of the precipitated bone flour and the steamed bone flour fed in Lots 1 and 4, respectively.

BALANCES OF MINERAL ELEMENTS AND NITROGEN

The average daily amounts of the constituents of the rations and of the resulting excreta, in grams per pig per day, are recorded in Tables III, IV, and V, pages 47 to 49; and the balance data for the five periods are set forth in Tables VI to X, pages 50 to 54, each table comprising the records from the four pigs which received the same treatment. Table XI, page 55, consists of averages of results from the four pigs, in the five periods, thus constituting a general summary table; and Table XII, page 56, states the average intake and retention per kilogram of live weight.

In considering the balance data from the four pigs on a single treatment the reader may profitably bear in mind the facts that Pigs 1, 3 and 4 were of about the same weight at the beginning of the experiment, and gained about alike thereafter, so that results from these three are closely comparable in all periods. Pig 2 was considerably the heaviest pig at the beginning, and remained so throughout the experiment. Since the mineral supplements were all fed in amounts furnishing 5 grams of calcium per pig per day, the smaller pigs were more liberally supplied with this nutrient, in excess of their maintenance requirement, than was No. 2, the heaviest individual, thus permitting more extensive storage. In three periods out of the five this pig retained less calcium than any of the other three, and in the other two periods ranked next to the lowest in calcium retention. This is as would be expected, since this element was present in amounts less than the optimum. The storage of phosphorus by this heaviest pig was also low, considering its size, not because of deficient supply, but because its retention was limited by the calcium content of the ration.

In regard to other elements, conditions differ among them as to amounts supplied in relation to requirements; sodium, for instance, was supplied in excess of the requirement, so that the heaviest pig usually retained the most; and the relatively extensive retention of potassium, nitrogen and sulphur also suggest that these elements were present in the rations in amounts such that the size of the heaviest pig constituted a factor making for heavy retention. This consideration, however, that is, the relative size of the pigs, is one which does not enter prominently into the determination of results.

Considering now the metabolism of the several elements—the balances of sodium, potassium, sulphur, phosphorus and nitrogen were all positive; that is, there was storage of each of these elements with each pig in each period; and the amounts supplied were probably sufficient for maximum retention on the plane of nutrition prevailing.

The retention of this group of elements naturally increased, in a general way, from period to period, until Period V was reached. Here the nitrogen and sulphur retention continued to increase, with increase in the size of the pigs; while in harmony with the very large measure of independence existing between the metabolism of protein and the mineral nutrients, the retention of sodium, potassium, magnesium and phosphorus all decreased, as determined by the great decrease in the intake and retention of calcium. This decrease in calcium metabolism had the effect to lower the whole plane of mineral nutrition. The general metabolism, as expressed by the retention, of five out of the eight elements studied, may thus be disposed of in one group.

Calcium, magnesium and chlorine remain for further discussion. Now calcium may be considered as the dominating mineral element. It is the one which is present in greatest proportion in the body; it can be absorbed from the alimentary tract in very large quantity by virtue of the capacity of the organism to remove it from solution in the blood through depositing it, along with phosphorus and magnesium, principally, in the skeleton; furthermore, this element was made the controlling factor in the mineral metabolism of this experiment by the large amounts added to the basal ration in Periods I to IV, and then withdrawn in Period V.

Calcium, then, was stored in large amounts in Periods I to IV, as permitted by the liberal intake. In Period V, with the reduction of the intake from 6.670 (Period IV) to 1.797 grams (averages) the retention naturally followed, with decrease from 3.403 to 0.024 grams. This is as would have been expected, except that in the light of results from previous work, especially as reported in Ohio Bulletin 271, we had reason to anticipate a negative calcium balance during Period V. We can explain the ability of the pigs to maintain calcium equilibrium during this period only by assuming that the long-continued previous feeding on high-calcium rations had the effect to reach over into the final period and to relieve, or reduce, in a measure, the calcium requirement.

Magnesium must have been present at all times in quantity greatly in excess of the requirement. The retention of magnesium by the four individuals varied widely. The reduction to a plane of magnesium equilibrium in Period V was determined by the same change in the calcium metabolism.

As to chlorine,—the experiment began with a period in which three out of four balances were negative and the other near to an equilibrium. In subsequent periods all chlorine balances were positive, and the retention increased regularly, from period to period, with increase in chlorine intake, as the pigs grew, and ate more feed. The chlorine of the rations was supplied by sodium chloride to the extent of two-thirds of the total. These results must be interpreted as signifying that the chlorine content of the rations fed in Period I was insufficient, and that in subsequent periods retention of chlorine became possible as the basal ration, in which the sodium chloride was contained in fixed proportion, was fed in increased amounts. The chlorine requirement did not increase proportionately with the general feed requirement; therefore, the pig lost chlorine on a low feed consumption and stored chlorine on a larger feed intake, the retention increasing regularly, from period to period, as above stated, as the feed consumption increased.

As to the values of these supplements, the primary purpose being to supply the calcium in which, alone, the basal ration is especially deficient, we would state first that since the mineral supplements furnished the same amount (5 grams) of calcium to each pig in each period where they were used (Periods I to IV), the differences in calcium intake are all due to the amounts of the basal ration consumed. Now, since the basal ration provided for virtually no retention of calcium, and since the retention of this element from the supplemented rations varied from 2.488 to 3.403 grams, it follows that the calcium of these supplements was retained in amounts equivalent to five-tenths to seven-tenths of the quantities thus supplied. Turning to Table XII, page 56, it will be observed that as the pigs increased in weight, from period to period, the intake per kilogram of live weight, and the retention as well, became less in each period than in the preceding one; the retention, however, decreased much less prominently than the intake. At the same time there was a progressive increase in the percentage of the intake which was retained. These data reflect the limitation of the amount of the intake, and seem to us not to afford safe basis for comparison of the supplements. Their striking feature is their uniformity—the lack of evidence of important differences. In the light of these observations the progressive increase in the absolute amount of calcium retained per pig per day as set forth in Table XI, page 55, indicates only increase in the size of the pigs. No significant differences, therefore, in the values of these supplements as sources of calcium for growing pigs were shown.

THE DISTRIBUTION OF THE OUTGO OF ELEMENTS BETWEEN URINE AND FECES

Referring to Table XIII, page 57, in 19 balances out of the 20 a greater proportion of the sodium was eliminated in the feces than in the urine, the feces sodium varying from an amount equal to that in the urine to one about seven times as great. Usually the feces sodium was from two to four times as great in amount as the urinary sodium. A fairly definite proportion usually prevailed with the four pigs on the same treatment.

At the same time the chlorine with which the sodium was fed was eliminated in each of the 20 balances in much greater quantity in the urine than in the feces, the urine chlorine being from ten to twenty-two times the amount of the feces chlorine.

This independence in the metabolism of sodium and chlorine has been commented upon in previous metabolism studies with swine and with cows in Ohio Experiment Station Bulletins 271, 295, 308 and 330. The compounds in which the extensive fecal elimination of sodium takes place have not been investigated.

Much the largest urinary elimination of sodium occurred in Period I, under the influence of the dicalcic salts contained in the precipitated bone flour.

The potassium was almost equally divided between urine and feces, with surprisingly little variation in the path of outgo. The difference between urine and feces potassium was as great as ten percent in only four cases out of twenty.

The calcium elimination was remarkably regular. The urinary calcium in the twenty balances varied between 2.7 and 6.0 percent of the total outgo. The urinary outgo was very slightly greater in Period I under the influence of the dicalcic salts of the precipitated bone flour than in other periods.

Magnesium was eliminated in the feces in amounts greater than in the urine in each of the twenty balances. The urinary elimination varied between 6.8 and 12.6 percent of the total.

Sulphur and nitrogen elimination followed the same order. Almost all of the figures for urinary sulphur and nitrogen were between 60 and 69 percent, the fecal outgo being over 40 percent in only three cases, and in no case less than 30 percent. The urinary nitrogen was usually a slightly higher proportion of that in the ration than was the urinary sulphur. These proportions were not affected by the mineral supplements fed.

Phosphorus likewise was almost constant in the method of its elimination. The urinary phosphorus varied between 22.9 and 34.2 percent of the total outgo, with no observable specific effects of mineral supplements.

The unusual regularity in the outgo of the eight elements studied is due to the maintenance of the same basal ration, throughout, and to the fact that the mineral supplements were much alike and were characterized by but slight differences in proportions of acid and basic constituents.

DIGESTIBILTY OF RATIONS

While there is no reason to anticipate an appreciable effect of the mineral supplements on the digestibility of the rations it has seemed worth while to establish very thoroughly the fact that there is no such effect, in order to be able to answer this question positively in case it should arise. Table XIV, page 59, shows that as usual there is no demonstrable influence of the calcium preparations fed upon the digestibility of the protein, carbohydrates and ether extract of the rations.

SUMMARY

1. This investigation was a study of the metabolism of growing swine on a cereal ration as affected by the supplementary addition of (1) precipitated bone flour, (2) precipitated bone flour and "special" steamed bone flour, half-and-half, (3) precipitated bone flour and pulverized limestone, 90 parts and 10, and (4) "special" steamed bone flour alone. In one period the basal ration was fed without mineral supplement.

2. All of these calcium supplements were of marked value. Calcium was retained in proportions of 0.5 to 0.7 of the amounts supplied. The investigation did not reveal any unmistakable differences in the assimilability of the calcium of these supplements.

3. The calcium balance on the basal ration of corn, wheat middlings and linseed oilmeal was practically an equilibrium, during rapid growth, when normally there is liberal calcium storage.

4. The intake of magnesium was superabundant; the balances were controlled by the associated calcium balance, with which they were in harmony.

5. Chlorine was supplied largely as sodium chloride, 1 gram of salt to 450 grams of feed. This proportion was insufficient during the first period, but provided for regularly increasing storage during the subsequent periods of more extensive feed consumption.

6. The balances of sodium, potassium, sulphur, phosphorus and nitrogen were all positive, the retention increasing with the growth of the pigs through all of the periods in which the mineral supplements were fed. In the fifth period, during which the unsupplemented cereal ration (the basal ration) was fed, the retention of sulphur and nitrogen continued to increase, but there was marked reduction of retention of sodium, potassium, magnesium and phosphorus, in harmony with and because of the marked decrease in the intake and retention of calcium.

7. Sodium, calcium, magnesium and phosphorus were eliminated in the feces in amounts greater than in the urine; sulphur, chlorine and nitrogen were eliminated in greater quantities in the urine than in the feces, while the elimination of potassium was about equally divided between the two excreta. The most extensive urinary elimination of sodium and calcium occurred under the influence of the dicalcic salts of the precipitated bone flour.

8. Especial attention is called to the large measure of independence observed in the metabolism of sodium and chlorine, and to the greater fecal than urinary elimination of sodium, since mistaken ideas regarding this matter rather commonly prevail.

TABLE I.—EXPERIMENT II: AVERAGE DAILY FOODS CONSUMED AND LIVE WEIGHTS OF PIGS (Grams)

Pig No., and days in period		Foods Consumed: Total grain ration (plus salt)	Corn	Linseed oilmeal	Wheat middlings	Common salt	Distilled water	Mineral supplement	Weight of pigs: Weight at beginning of period	Weight at end of period
PERIOD I										
1	10	1,610	1,249.5	178.5	178.5	3.542	2,699	18.552	48,000	54,200
2	10	2,042	1,584.7	226.4	226.4	4.492	3,890	18.552	59,200	62,700
3	10	1,690	1,311.6	187.4	187.4	3.718	2,771	18.552	50,300	56,000
4	10	1,660	1 288.3	184.0	184.0	3.652	2,805	18.552	49,100	51,900
PERIOD II										
1	10	2,126	1,649.9	235.7	235.7	4.677	2,637	18.027	56,200	63,700
2	10	2,504	1,943.3	277.6	277.6	5.509	3,111	18.027	66,400	73,500
3	10	2,224	1,726.0	246.6	246.6	4.893	2,658	18.027	57,800	64,500
4	10	2,048	1,589.4	227.1	227.1	4.506	2,573	18.027	54,500	61,100
PERIOD III										
1	10	2,678	2,078.3	296.9	296.9	5.892	3,265	19.544	67,800	76,500
2	10	3,170	2,460.1	351.5	351.5	6.974	3,615	19.544	79,000	89,100
3	10	2,746	2,131.1	304.4	304.4	6.041	3,230	19.544	69,200	77,900
4	10	2,574	1,997.6	285.4	285.4	5.663	3,155	19.544	64,900	73,700
PERIOD IV										
1	10	2,678	2,078.3	296.9	296.9	5.892	3 151	16.779	83,600	91,100
2	10	3,170	2,460.1	351.5	351.5	6.974	3,640	16.779	95,600	106,500
3	10	2,746	2,131.1	304.4	304.4	6.041	3,170	16.779	84,000	90,900
4	10	2,574	1,997.6	285.4	285.4	5.663	3,110	16.779	79,400	86 300
PERIOD V										
1	10	2,914	2,261.5	323.1	323.1	6.411	3,125	0.000	96,200	102,900
2	10	3,436	2,666.6	380.9	380.9	7.559	3,700	0.000	108,700	116,000
3	10	2,908	2,256.8	322.4	322.4	6.398	3,075	0.000	97,100	104,600
4	10	2,762	2,143.5	306.2	306.2	6.076	3,060	0.000	92,700	99 500

TABLE II.—EXPERIMENT II: COMPOSITION OF FOODS (Percent)

Food	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Ash	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon
Corn	86.65	3.966	1.7033	1.3110	8.1938	71.4836	1.3033	0.0067	0.3474	0.0135	0.1163	0.1300	0.0408	0.2647	0.0182
Linseed oilmeal	90.58	6.598	4.0567	6.1680	38.5500	36.5142	4.8611	0.0591	1.0905	0.3463	0.5222	0.4185	0.0389	0.7470	0.0633
Wheat middlings	89.30	4.642	3.6200	2.4470	15.2938	61.2455	4.4987	0.0705	1.1355	0.0987	0.3685	0.2015	0.0369	1.0365	0.0226
Common salt, C. P.	99.96	....	....	....	....	....	....	39.3187	....	....	....	....	60.6192	....	....
Precipitated bone flour	92.24	0.262	....	0.1656	1.0350	....	77.98	0.1508	0.0918	26.9520	0.7864	0.3110	2.0727	16.1644	0.3400
Prec. bone 50 %; steamed bone 50 %	90.05	0.172	....	0.5666	3.5413	....	77.60	0.2509	0.0772	27.7360	0.8208	0.3135	1.0471	15.3040	0.3400
Prec. bone 90 %; pulv. limestone 10 %	91.13	0.198	....	0.1372	0.8575	....	75.53	0.1068	0.0836	25.5840	2.1144	0.2845	1.8697	14.6933	0.4575
Steamed bone flour	96.96	2.194	....	1.1626	7.2663	....	83.38	0.3755	0.1415	29.8000	0.9264	0.3165	0.0597	13.9800	0.8575

TABLE III.—EXPERIMENT II: CONSTITUENTS OF DAILY RATIONS (Grams)

Pig No.	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Silicon
PERIOD I														
1	1420.89	69.68	34.98	31.80	198.68	1067.69	1.736	8.332	5.963	3.189	2.788	3.177	9.489	0.443
2	1797.50	88.35	44.37	40.31	251.95	1354.13	2.194	10.562	6.221	4.005	3.520	3.927	11.232	0.545
3	1490.71	73.13	36.72	33.38	208.56	1120.78	1.821	8.745	6.011	3.341	2.924	3.316	9.813	0.463
4	1464.40	71.82	36.06	32.77	204.82	1100.80	1.789	8.589	5.993	3.283	2.873	3.265	9.690	0.455
PERIOD II														
1	1869.85	91.96	46.19	42.04	262.74	1409.83	2.300	10.992	6.272	4.167	3.660	3.876	11.330	0.563
2	2199.45	108.31	54.41	49.49	309.34	1660.52	2.701	12.944	6.497	4.881	4.302	4.532	12.854	0.654
3	1955.39	96.20	48.33	43.97	274.83	1474.88	2.301	11.499	6.330	4.352	3.827	4.046	11.726	0.587
4	1801.96	88.59	44.50	40.51	253.15	1358.17	2.217	10.592	6.225	4.019	3.529	3.741	11.016	0.545
PERIOD III														
1	2352.72	115.84	58.19	52.86	330.32	1775.89	2.861	13.845	6.602	5.474	4.598	5.010	13.668	0.722
2	2781.77	137.12	68.88	62.56	391.01	2102.20	3.384	16.386	6.896	6.405	5.432	5.864	15.653	0.838
3	2411.97	118.77	59.67	54.20	338.69	1820.97	2.934	14.194	6.642	5.603	4.712	5.126	13.942	0.739
4	2262.11	111.34	55.94	50.80	317.52	1706.96	2.752	13.309	6.540	5.278	4.420	4.829	13.250	0.699
PERIOD IV														
1	2351.18	116.17	58.19	53.03	331.37	1775.89	2.903	13.853	6.602	5.216	4.595	4.655	13.142	0.777
2	2780.23	137.45	68.88	62.73	392.06	2102.20	3.426	16.394	6.896	6.147	5.429	5.509	15.127	0.893
3	2410.43	119.10	59.67	54.37	339.74	1820.97	2.976	14.202	6.642	5.345	4.709	4.771	13.416	0.794
4	2260.57	111.67	55.94	50.97	318.57	1706.96	2.794	13.317	6.540	5.020	4.417	4.474	12.724	0.754
PERIOD V														
1	2540.78	126.01	63.33	57.49	359.27	1932.46	3.092	15.048	1.743	5.508	4.941	5.054	11.749	0.690
2	2995.77	148.57	74.66	67.77	423.59	2278.54	3.645	17.743	2.055	6.494	5.826	5.959	13.851	0.812
3	2535.45	125.74	63.19	57.37	358.52	1928.42	3.085	15.017	1.739	5.497	4.931	5.043	11.724	0.689
4	2408.14	119.42	60.01	54.48	340.50	1831.59	2.930	14.263	1.651	5.220	4.682	4.790	11.135	0.653

TABLE IV.—EXPERIMENT II: CONSTITUENTS OF AVERAGE DAILY URINE (Grams)

Pig No.	Nitrogen	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus
PERIOD I								
1	14.810	0.483	3.416	0.138	0.247	1.300	2.912	2.150
2	18.946	0.727	3.844	0.244	0.394	1.681	4.008	3.237
3	15.491	0.448	4 321	0.112	0.214	1.418	3.332	2.082
4	15.507	0.450	3.628	0.155	0.313	1.412	3.556	2.581
PERIOD II								
1	20.168	0.204	4.858	0.107	0.325	1.741	3.323	2.522
2	23.429	0.316	5.425	0.131	0.397	2.034	3.617	3.218
3	19.733	0.240	5.163	0.101	0.351	1.791	3.496	2.218
4	19.345	0.248	4.729	0.116	0.444	1 686	3.153	2.526
PERIOD III								
1	25.565	0.208	5.849	0.135	0.455	2.136	4.046	3.275
2	30.966	0.386	7.127	0.135	0.585	2.608	4.635	4.195
3	25.056	0.276	6.655	0.106	0.526	2.187	4.303	2.972
4	23.328	0.314	5.514	0.126	0.557	1.981	3.953	2.922
PERIOD IV								
1	26.497	0.537	6.040	0.103	0.462	2.131	3.763	3.622
2	31.932	0 253	7.849	0.106	0.687	2.580	4.131	3.882
3	27.713	0.663	7.460	0.089	0.591	2.259	4.000	3.142
4	24.397	0.326	6.413	0.094	0 610	2.003	3.807	3.030
PERIOD V								
1	27.792	0.633	7.200	0.058	0.515	2.258	3.943	3.408
2	35.428	0 622	8.435	0.098	0.735	2.744	4.892	3.966
3	28.443	0.425	7.650	0 063	0.562	2.283	3.968	3.479
4	26.017	0.418	7.080	0.063	0.585	2.093	3.894	3.180

TABLE V.—EXPERIMENT II: CONSTITUENTS OF AVERAGE DAILY FECES (Grams)

Pig No.	Total weight	Dry matter	Ether extract	Crude fiber	Nitrogen	Protein	Nitrogen-free extract	Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus
PERIOD I														
1	8,361	231.767	32.105	27.904	7.284	45.609	95.322	0.671	3.934	3.229	2.820	0.734	0.197	5.484
2	11,600	338.720	51.530	38.441	12.106	75.661	135.623	0.686	5.858	3.811	3.554	1.066	0.414	6.232
3	8,282	266.266	36.316	30.547	8.943	55.894	110.685	0.650	3.723	3.345	2.946	0.773	0.209	5.938
4	8 121	261.415	39.957	31.367	8.718	54.487	104.650	0.682	4.181	3.201	2.775	0.752	0.241	5.376
PERIOD II														
1	10,763	285.220	42.509	37.313	9.208	57.549	111.170	0.929	4.854	3.157	3.528	0.924	0.242	6.333
2	13,216	386.332	68.429	50.266	12.637	78.983	144.814	1 175	6.149	3.950	4.201	1.323	0.340	7.634
3	11,101	344.353	53.959	42.666	12 554	78.463	128.267	1.117	5.039	3.663	3.858	1.203	0.278	7.462
4	9,571	305.219	55.233	29.899	10.088	63.049	121.013	0.786	4.795	3.067	3.512	1.021	0.240	6.160
PERIOD III														
1	14,393	393.361	45.919	41.412	12.450	77.813	181.621	1.405	6.523	3.426	4.878	1.388	0.360	8.285
2	15,442	468.201	60.205	51.700	14.857	92 854	210.752	1.635	7.570	3.627	5.573	1.628	0.385	8.882
3	13,535	401.313	42.390	43.456	14.298	89.365	179.676	1.519	7.958	3.317	4.896	1.439	0.301	8.347
4	12,171	383.752	47.670	39.394	13.369	83.554	169.921	1.267	6.361	3.089	4.520	1.437	0.262	7.749
PERIOD IV														
1	14,144	377.362	43.523	41.475	12.530	78.314	169.746	1.132	6.438	3.303	4.656	1.564	0.276	7.222
2	14,880	448.334	53.333	47.676	14.130	88.313	208.061	1.610	6.873	3.376	5.266	1.570	0.301	8.803
3	13,077	370.995	49.636	39.197	12.425	77.653	160.924	1.333	5.324	3.114	4.582	1.218	0.243	7.676
4	10,685	352.071	48.739	37.614	11.745	73.406	150.778	1.264	5.441	2.882	4.249	1.184	0.202	7.020
PERIOD V														
1	15,682	410.868	65.352	44.656	13.645	85.280	173.206	2.170	6.618	1.477	5.890	1.347	0.274	7.350
2	17,474	512.687	78.139	56.487	17.551	109.693	217.467	2.224	7.855	2.244	5.747	1.735	0.432	8.961
3	14,114	409.871	62.127	45.240	14.636	91.477	169.855	2.018	5.903	1.605	4.955	1.431	0.301	7.311
4	11,557	381.150	60.111	38.543	13.287	83.044	159.481	1.597	5.755	1.486	4.747	1.244	0.179	7.034

TABLE VI.—EXPERIMENT II, PERIOD I: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Food Urine Feces Balance
1	Corn 1249.5, linseed oilmeal 178.5, wheat middlings 178.5, common salt 3.542, precipitated bone flour 18.552	Precipitated bone flour	1.736 0.483 0.671 0.582	8.332 3.416 3.934 0.982	5.963 0 138 3.229 2.596	3 189 0.247 2.820 0.122	2 788 1.300 0.734 0.754	3.177 2.912 0.197 0 068	9.489 2.150 5.484 1.855	31.800 14.810 7.284 9.706
2	Corn 1584.7, linseed oilmeal 226.4, wheat middlings 226.4, common salt 4.492, precipitated bone flour 18.552	Precipitated bone flour	2.194 0.727 0.686 0.781	10.562 3 844 5.858 0.860	6.221 0.244 3 811 2 166	4.005 0.394 3.554 0.057	3.520 1.681 1.066 0.773	3.927 4.008 0.414 —0.495	11.232 3.237 6.232 1.763	40.310 18.946 12.106 9 258
3	Corn 1311.6, linseed oilmeal 187.4, wheat middlings 187.4, common salt 3.718, precipitated bone flour 18.552	Precipitated bone flour	1 821 0.448 0.650 0.723	8.745 4.321 3.723 0.701	6.011 0.112 3.345 2.554	3.341 0.214 2.946 0.181	2.924 1.418 0.773 0 733	3.316 3.332 0.209 —0.225	9.813 2.082 5.938 1.793	33.380 15.491 8.943 8.946
4	Corn 1288.3, linseed oilmeal 184.0, wheat middlings 184.0, common salt 3.652, precipitated bone flour 18.552	Precipitated bone flour	1.789 0.450 0.682 0.657	8.589 3.628 4.181 0.780	5.993 0.155 3.201 2.637	3.283 0.313 2.775 0.195	2.873 1.412 0.752 0.709	3.265 3.556 0.241 —0.532	9.690 2.581 5.376 1.733	32.770 15.507 8.718 8.545

TABLE VII.—EXPERIMENT II, PERIOD II: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Food Urine Feces Balance
1	Corn 1649.9, linseed oilmeal 235.7, wheat middlings 235.7, common salt 4.677, precipitated bone-steamed bone (50:50) 18.027	Precipitated bone-steamed bone	2.300 0.204 0.929 1.167	10.992 4.858 4.854 1.280	6.272 0.107 3.157 3.008	4.167 0.325 3.528 0.314	3.660 1.741 0.924 0.995	3.876 3.323 0.242 0.311	11.330 2.522 6.333 2.475	42.04 20.168 9.208 12.664
2	Corn 1943.3, linseed oilmeal 277.6, wheat middlings 277.6, common salt 5.509, precipitated bone-steamed bone (50:50) 18.027	Precipitated bone-steamed bone	2.701 0.316 1.175 1.210	12.944 5.425 6.149 1.370	6.497 0.131 3.950 2 416	4.881 0.397 4.201 0.283	4.302 2.034 1.323 0.945	4.532 3.617 0.340 0.575	12.854 3.218 7.633 2.003	49.49 23.429 12.637 13.424
3	Corn 1726.0, linseed oilmeal 246.6, wheat middlings 246.6, common salt 4.893, precipitated bone-steamed bone (50:50) 18.027	Precipitated bone-steamed bone	2.301 0.240 1.117 0.944	11.499 5.163 5.039 1.297	6.330 0.101 3.663 2.566	4.352 0.351 3.858 0.143	3.827 1.791 1.203 0.833	4.046 3.496 0.278 0.272	11.726 2.218 7.462 2.046	43.97 19.733 12.554 11.683
4	Corn 1589.4, linseed oilmeal 227.1, wheat middlings 227.1, common salt 4.506, precipitated bone-steamed bone (50:50) 18.027	Precipitated bone-steamed bone	2.217 0.248 0.786 1.183	10.592 4.729 4 795 1.068	6.225 0.116 3.068 3.041	4.019 0.444 3.512 0 063	3.529 1.686 1.021 0.822	3.741 3.153 0.240 0.348	11.016 2.526 6.160 2.330	40.51 19.345 10.088 11.077

TABLE VIII.—EXPERIMENT II, PERIOD III: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Eood Urine Feces Balance
1	Corn 2078.3, linseed oilmeal 296.9, wheat middlings 296.9, common salt 5.892, precipitated bone pulverized limestone (90:10) 19.544	Precipitated bone-pulverized limestone	2.861 0.208 1.405 1.248	13.845 5.849 6.523 1.473	6.602 0.135 3.426 3.041	5.474 0.455 4.878 0.141	4.598 2.136 1.388 1.074	5.010 4.046 0 360 0.604	13.668 3.275 8.285 2.108	52.86 25.565 12.450 14.845
2	Corn 2460.1, linseed oilmeal 351.5, wheat middlings 351.5, common salt 6.974, precipitated bone-pulverized limestone (90:10) 19.544	Precipitated bone-pulverized limestone	3.384 0.386 1.635 1.363	16.386 7.127 7.570 1.689	6.896 0.135 3.627 3.134	6.405 0.585 5.573 0.247	5.432 2.608 1.628 1.196	5.864 4.635 0.385 0.844	15.653 4.195 8.882 2.576	62.56 30.966 14.857 16.737
3	Corn 2131.1, linseed oilmeal 304.4, wheat middlings 304.4, common salt 6.041, precipitated bone-pulverized limestone (90:10) 19.544	Precipitated bone-pulverized limestone	2.934 0.276 1.519 1.139	14.194 6.655 5.958 1.581	6.642 0.106 3.317 3.219	5.603 0.526 4.896 0.181	4.712 2.187 1.439 1.086	5.126 4.303 0.301 0.522	13.942 2.972 8.347 2.623	54.20 25.056 14.298 14.846
4	Corn 1997.6, linseed oilmeal 285.4, wheat middlings 285.4, common salt 5.663, precipitated bone-pulverized limestone (90:10) 19.544	Precipitated bone-pulverized limestone	2.752 0.314 1.267 1.171	13.309 5.514 6.361 1.434	6.540 0.126 3.089 3.325	5.278 0.557 4.520 0.201	4.420 1.981 1 437 1.002	4.829 3.953 0.262 0.614	13.250 2.922 7.749 2.579	50.80 23.328 13.369 14.103

TABLE IX.—EXPERIMENT II, PERIOD IV: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Food Urine Feces Balance
1	Corn 2078.3, linseed oilmeal 296.9, wheat middlings 296.9, common salt 5.892, steamed bone flour 16.779	Steamed bone flour	2.903 0.537 1.132 1.234	13.853 6.040 6.438 1.375	6.602 0.103 3.303 3.196	5.216 0.462 4.656 0.098	4.595 2.131 1.564 0.900	4.655 3.763 0.276 0.616	13.142 3.622 7.222 2.298	53.03 26.497 12.530 14.003
2	Corn 2460.1, linseed oilmeal 351.5, wheat middlings 351.5, common salt 6.974, steamed bone flour 16.779	Steamed bone flour	3.426 0.253 1.610 1.563	16.394 7.849 6.873 1.672	6.896 0.106 3.376 3.414	6.147 0.687 5.266 0.194	5.429 2 580 1.570 1.270	5.509 4.131 0.301 1.077	15.127 3.882 8.803 2.442	62.73 31.932 14.130 16.668
3	Corn 2131.1, linseed oilmeal 304.4, wheat middlings 304.4, common salt 6.041, steamed bone flour 16.779	Steamed bone flour	2.976 0.663 1.333 0.980	14.202 7.460 5.324 1.418	6.642 0.089 3.114 3.439	5.345 0.591 4.582 0.172	4.709 2.259 1.218 1.232	4.771 4.000 0.243 0.528	13.416 3.142 7.676 2.598	54.37 27.713 12.425 14.232
4	Corn 1997.6, linseed oilmeal 285.4, wheat middlings 285.4, common salt 5.663, steamed bone flour 16.779	Steamed bone flour	2.794 0.326 1.264 1.204	13.317 6.413 5.441 1.463	6.540 0.094 2.882 3.564	5.020 0.610 4.249 0.161	4.417 2.003 1.184 1.230	4.474 3.807 0.202 0.465	12.724 3.030 7.020 2.674	50.97 24.397 11.745 14.828

TABLE X.—EXPERIMENT II, PERIOD V: AVERAGE DAILY RATIONS AND BALANCES OF MINERALS AND NITROGEN (Grams)

Pig No.	Average daily rations	Distinguishing features of rations	Sodium Food Urine Feces Balance	Potassium Food Urine Feces Balance	Calcium Food Urine Feces Balance	Magnesium Food Urine Feces Balance	Sulphur Food Urine Feces Balance	Chlorine Food Urine Feces Balance	Phosphorus Food Urine Feces Balance	Nitrogen Food Urine Feces Balance
1	Corn 2261.5, linseed oilmeal 323.1, wheat middlings 323.1, common salt 6.411	Basal ration	3.092 0.633 2.170 0.289	15.048 7.200 6.618 1.230	1.743 0.058 1.477 0.208	5.508 0.515 4.890 0.103	4.941 2.258 1.347 1.336	5.054 3.943 0.274 0.837	11.749 3.408 7.350 0.991	57.49 27.792 13.645 16.053
2	Corn 2666.6, linseed oilmeal 380.9, wheat middlings 380.9, common salt 7.559	Basal ration	3.645 0.622 2.224 0.799	17.743 8.435 7.855 1.453	2.055 0.098 2.244 —0.287	6.494 0.735 5.747 0.012	5.826 2.744 1.735 1.347	5.959 4.892 0.432 0.635	13.851 3.966 8.961 0.924	67.77 35.428 17.551 14.791
3	Corn 2256.8, linseed oilmeal 322.4, wheat middlings 322.4, common salt 6.398	Basal ration	3.085 0.425 2.018 0.642	15.017 7.650 5.903 1.464	1.739 0.063 1.605 0.071	5.497 0.562 4.955 —0.020	4.931 2.283 1.431 1.217	5.043 3.968 0.301 0.774	11.724 3.479 7.311 0.934	57.37 28.443 14.636 14.291
4	Corn 2143.5, linseed oilmeal 306.2, wheat middlings 306.2, common salt 6.076	Basal ration	2.930 0.418 1.597 0.915	14.263 7.080 5.755 1.428	1.651 0.063 1.486 0.102	5.220 0.585 4.747 —0.112	4.682 2.093 1.244 1.345	4.790 3.894 0.179 0.717	11.135 3.180 7.034 0.921	54.48 26.017 13.287 15.176

TABLE XI.—EXPERIMENT II: DAILY RATIONS AND MINERAL BALANCES—AVERAGES FOR FOUR PIGS (Grams)

Period No.	Distinguishing feature of rations		Sodium	Potassium	Calcium	Magnesium	Sulphur	Chlorine	Phosphorus	Nitrogen
I	Precipitated bone flour	Food	1.885	9.057	6.047	3.455	3.026	3.421	10.056	34.565
		Urine	0.527	3.802	0.162	0.292	1.453	3.452	2.513	16.189
		Feces	0.672	4.424	3.397	3 024	0.831	0.265	5.758	9.263
		Balance	+0.686	+0.831	+2.488	+0.139	+0.742	—0.296	+1.786	+9.114
II	Precipitated bone-steamed bone	Food	2.380	11.507	6.331	4.355	3.830	4.049	11.732	44.003
		Urine	0.252	5.044	0.114	0.379	1.813	3.397	2.621	20.669
		Feces	1.002	5.209	3.460	3.775	1.118	0.275	6.897	11.122
		Balance	+1.126	+1.254	+2.758	+0.201	+0.899	+0.377	+2.214	+12.212
III	Precipitated bone-pulverized limestone	Food	2.983	14.434	6.670	5.690	4.791	5.207	14.128	55.110
		Urine	0.296	6.287	0.126	0.530	2.228	4.234	3.341	26.229
		Feces	1.456	6.603	3.365	4.967	1.473	0.327	8.316	13.744
		Balance	+1.231	+1.544	+3.180	+0.193	+1.090	+0.646	+2.472	+15.133
IV	Steamed bone flour	Food	3.025	14.442	6.670	5.432	4 790	4.852	13.602	55.280
		Urine	0.445	6.940	0.098	0.590	2.243	3.925	3.419	27.635
		Feces	1.335	6.019	3.169	4.688	1.384	0.256	7.680	12.708
		Balance	+1.245	+1.483	+3.403	+0.156	+1.160	+0.672	+2.503	+14.933
V	Basal ration	Food	3.188	15.518	1.797	5.680	5.095	5.212	12.115	59.280
		Urine	0.525	7.591	0.071	0.599	2.345	4.174	3.508	29.420
		Feces	2.003	6.533	1.703	5.085	1.439	0.297	7.664	14.780
		Balance	+0.660	+1 394	+0.024	—0.004	+1.311	+0.741	+0.943	+15.078

TABLE XII.—EXPERIMENT II: INTAKE AND RETENTION OF MINERAL ELEMENTS AND NITROGEN PER KILOGRAM OF LIVE WEIGHT; INTAKE AND RETENTION IN GRAMS; PERCENT RETENTION BASED ON INTAKE; DATA REPRESENT AVERAGES FOR FOUR PIGS

Period No. Ave. live weight	Distinguishing features of rations	Sodium Intake Retention Percent Ret.	Potassium Intake Retention Percent Ret.	Calcium Intake Retention Percent Ret.	Magnesium Intake Retention Percent Ret.	Sulphur Intake Retention Percent Ret.	Chlorine Intake Retention Percent Ret.	Phosphorus Intake Retention Percent Ret.	Nitrogen Intake Retention Percent Ret.
I 53.925	Precipitated bone flour	0.035 +0.013 +36.4%	0.168 +0.015 +9.2%	0.112 +0.046 +41.1%	0.064 +0.003 +4.0%	0.056 +0.014 +24.5%	0.063 —0.005 —8.7%	0.186 +0.033 +17.8%	0.641 +0.169 +26.4%
II 62.213	Precipitated bone-steamed bone	0.038 +0.018 +47.3%	0 185 +0.020 +10.9%	0.102 +0.044 +43.6%	0.070 +0.003 +4.6%	0.062 +0.015 +23.5%	0.065 +0.006 +9.3%	0.189 +0.036 +18.9%	0.707 +0.196 +27.8%
III 74.763	Precipitated bone-pulverized limestone	0.040 +0.016 +41.3%	0 193 +0.021 +10.7%	0.089 +0.043 +47.7%	0.076 +0.003 +3.4%	0.064 +0.015 +22.8%	0.070 +0.009 +12.4%	0.189 +0.033 +17.5%	0.737 +0 202 +27.5%
IV 89.675	Steamed bone flour	0.034 +0.014 +41.2%	0.161 +0.017 +10.3%	0.074 +0.038 +51.0%	0.061 +0.002 +2.9%	0.053 +0.013 +24.2%	0.054 +0.007 +13.9%	0.152 +0.028 +18.4%	0.616 +0.167 +27.0%
V 102.213	Basal ration	0.031 +0.006 +20.7%	0.152 +0.014 +9.0%	0 018 +0.0002 +1.3%	0.056 —0.000 —0.1%	0.050 +0.013 +25.7%	0.051 +0.007 +14.2%	0.119 +0.009 +7.8%	0.580 +0.148 +25.4%

TABLE XIII.—EXPERIMENT II: DISTRIBUTION OF OUTGO OF ELEMENTS BETWEEN URINE AND FECES (Percent)

Pig No.	Distinguishing features of rations	Sodium Urine	Sodium Feces	Potassium Urine	Potassium Feces	Calcium Urine	Calcium Feces	Magnesium Urine	Magnesium Feces	Sulphur Urine	Sulphur Feces	Chlorine Urine	Chlorine Feces	Phosphorus Urine	Phosphorus Feces	Nitrogen Urine	Nitrogen Feces
PERIOD I																	
1	Precipitated bone flour	41.9	58.1	46.5	53.5	4.1	95.9	8.1	91.9	63.9	36.1	93.7	6.3	28.2	71.8	67.0	33.0
2	Precipitated bone flour	51.5	48.5	39.6	60.4	6.0	94.0	10.0	90.0	61.2	38.8	90.6	9.4	34.2	65.8	61.0	39.0
3	Precipitated bone flour	40.8	59.2	53.7	46.3	3.2	96.8	6.8	93.2	64.7	35.3	94.1	5.9	26.0	74.0	63.4	36.6
4	Precipitated bone flour	39.7	60.3	46.5	53.5	4.6	95.4	10.1	89.9	65.2	34.8	93.7	6 3	32.4	67.6	64.0	36.0
PERIOD II																	
1	Precipitated bone-steamed bone	18.0	82.0	50.0	50.0	3.3	96.7	8 4	91.6	65.3	34.7	93.2	6.8	28.5	71 5	68.7	31.3
2	Precipitated bone-steamed bone	21.2	78.8	46.9	53.1	3.2	96.8	8.6	91.4	60.6	39.4	91.4	8.6	29.7	70.3	65.0	35.0
3	Precipitated bone-steamed bone	17.7	82.3	50.6	49 4	2.7	97.3	8.3	91.7	59.8	40.2	92.6	7.4	22.9	77.1	61.1	38.9
4	Precipitated bone-steamed bone	24.0	76.0	49.7	50.3	3.6	96.4	11.2	88 8	62 3	37.7	92 9	7.1	29.1	70 9	65.7	34.3
PERIOD III																	
1	Precipitated bone-pulverized limestone	12.9	87.1	47.3	52.7	3.8	96.2	8.5	91.5	60.6	39.4	91.8	8.2	28.3	71.7	67.2	32.8
2	Precipitated bone-pulverized limestone	19 1	80.9	48.5	51.5	3.6	96.4	9.5	90.5	61.6	38.4	92.3	7.7	32.1	67.9	67.6	32.4
3	Precipitated bone-pulverized limestone	15.4	84 6	52.8	47.2	3.1	96.9	9.7	90.3	60.3	39.7	93.5	6.5	26.3	73.7	63.7	36.3
4	Precipitated bone-pulverized limestone	19.8	80.2	46.4	53.6	3.9	96.1	11.0	89.0	58.0	42.0	93.8	6.2	27.4	72.6	63.6	36.4

TABLE XIII.—EXPERIMENT II: DISTRIBUTION OF OUTGO OF ELEMENTS BETWEEN URINE AND FECES (Percent)—Concluded

Pig No.	Distinguishing features of rations	Sodium Urine Feces	Potassium Urine Feces	Calcium Urine Feces	Magnesium Urine Feces	Sulphur Urine Feces	Chlorine Urine Feces	Phosphorus Urine Feces	Nitrogen Urine Feces
PERIOD IV									
1	Steamed bone flour	32.2 67.8	48.4 51.6	3.0 97.0	9.0 91.0	57.7 42.3	93.2 6.8	33.4 66.6	67.9 32.1
2	Steamed bone flour	13.6 86.4	53.3 46.7	3.0 97.0	11.5 88.5	62.2 37.8	93.2 6.8	30.6 69.4	69.3 30.7
3	Steamed bone flour	33.2 66.8	58.4 41.6	2.8 97.2	11.4 88.6	65.0 35.0	94.3 5.7	29.0 71.0	69.0 31.0
4	Steamed bone flour	20.5 79.5	54.1 45.9	3.2 96.8	12.6 87.4	62.8 37.2	95.0 5.0	30.1 69.9	67.5 32.5
PERIOD V									
1	Basal ration	22.6 77.4	52.1 47.9	3.8 96.2	9.5 90.5	62.6 37.4	93.5 6.5	31.7 68.3	67.1 32.9
2	Basal ration	21.8 78.2	51.8 48.2	4.2 95.8	11.3 88.7	61.3 38.7	91.9 8.1	30.7 69.3	66.9 33.1
3	Basal ration	17.4 82.6	56.4 43.6	3.8 96.2	10.2 89.8	61.5 38.5	92.9 7.1	32.2 67.8	66.0 34.0
4	Basal ration	20.8 79.2	55.2 44.8	4.1 95.9	11.0 89.0	62.7 37.3	95.6 4.4	31.1 68.9	66.2 33.8

TABLE XIV.—EXPERIMENT II: COEFFICIENTS OF DIGESTIBILITY OF RATIONS

Pig No.	Distinguishing features of rations	Protein	Nitrogen-free extract	Ether extract
Period I				
1	Precipitated bone flour	77.0	91.1	53.9
2		70.0	90.0	41.7
3		73.2	90.1	50.3
4		73.4	90.5	44.4
Period II				
1	Precipitated bone-steamed bone	78.1	92.1	53.8
2		74.5	91.3	36.8
3		71.5	91.3	43.9
4		75.1	91.1	37.7
Period III				
1	Precipitated bone-pulverized limestone	76.4	89.8	60.4
2		76.3	90.0	56.1
3		73.6	90.1	64.3
4		73.7	90.0	57.2
Period IV				
1	Steamed bone flour	76.4	90.4	62.
2		77.5	90.1	61.2
3		77.1	91.2	58.3
4		77.0	91.2	56.4
Period V				
1	Basal ration	76.3	91.0	48.1
2		74.1	90.5	47.4
3		74.5	91.2	50.6
4		75.6	91.3	49.7

3. EFFECTS OF MINERAL SUPPLEMENTS ON THE DEVELOPMENT OF SWINE—I

This experiment, conducted between April 30 and July 24, 1917, was a study of the effects of a cereal ration and of four calcium phosphate and carbonate supplements on the growth of young swine, with especial reference to the skeleton.

Thirty pigs were used, five being killed at the beginning of the experimental feeding, thus serving as a control; five more were fed the basal ration alone, constituting a second control; and twenty pigs in four lots of five each were fed on the basal ration plus the four mineral supplements which were compared.

The basal ration was composed of corn 350 parts, wheat middlings 50 parts, linseed oilmeal 50 parts, and salt 1 part. We have spoken of this as a cereal ration. Accurately speaking this is a seed ration, but not wholly a cereal ration, since flax, from which the linseed oilmeal is prepared, is not a cereal; but the prominent characteristics and deficiencies of all seed rations are so much alike that for our purpose it is not misleading to speak of this as a cereal ration.

The mineral supplements used were commercial precipitated calcium carbonate, special steamed bone flour, precipitated bone flour and rock phosphate floats. The carbonate was a precipitated product of impure technical grade; the special steamed bone flour was, as in the previous studies, bone floats from the grinding of special steamed bone, a refined by-product of gelatine manufacture; the precipitated bone flour was also a by-product resulting from the manufacture of gelatine; and the rock phosphate floats was the ordinary phosphatic limestone as used for land fertilizing purposes.

The pigs used were purebred Duroc-Jerseys, and were spring pigs of the season in which this experiment was started. The average initial weights of the several lots were 62.12 to 62.13 kilograms per pig; the average final weight, 86 days thereafter, 108.96 to 116.56 kilograms (239.7 to 256.4 pounds), and the average daily gain in weight 0.533 to 0.626 kilogram (1.17 to 1.38 pounds). The average daily feed consumed in the several lots was 2.620 and 2.673 kilograms (5.76 to 5.88 pounds), the feed consumption being arbitrarily maintained as nearly as possible the same in each lot. The mineral supplements were administered mixed with the ration, which was fed as a slop.

After determining by trial the proper amounts of mineral supplements to feed, the pigs were given such quantities as provided 5 grams of calcium per head per day. These amounts of the supplements were 38.98 grams of calcium carbonate, 42.33 grams of steamed bone flour, 48.38 grams of precipitated bone flour, and 44.95 grams of rock phosphate floats per lot of five pigs, per feed, the pigs being fed twice per day. At first we fed double these quantities, but it was necessary to reduce the amounts on account of the pigs which received the carbonate. These pigs showed unmistakably that 10 grams of calcium per head per day in this form was excessive, this fact becoming apparent after 6 days' feeding on the larger amount. After the reduction in the amount fed there was no further evidence of digestive disorder, though the behavior of the pigs receiving the carbonate suggested that this preparation was fed about to the limit of tolerance for protracted periods.

The calcium contents of the mineral supplements, in percent, were as follows: Calcium carbonate, 32.07; steamed bone, 29.53; precipitated bone, 25.84; and rock phosphate floats, 27.81.

The average daily gain in live weight in the several lots as set forth in Table I, page 66, shows that Lot 4 (rock phosphate) made the least gain in weight, while the other three lots gained about equally. From metabolism studies with these same preparations we have learned that the rock phosphate is less thoroughly utilized than the other more readily soluble preparations with which it is here compared. On this account, if these preparations have a value as affecting the gain in weight, we would naturally conclude that the fact that the rock phosphate lot made the smallest gain was due to their receiving this supplement. When we consider, however, the fact that Lot 5, which received only the basal ration, without mineral supplement, made as large a gain in weight as Lots 2 and 3, which received the two bone flours, it is apparent that these mineral supplements have no appreciable effect on the rate of gain from a given amount of feed. The number of pigs involved, however, was not sufficient to make interpretation certain on this point.

The percent of gross dressed to live weight in the several lots of pigs, excluding the control lot, varied from 79.87 to 81.69 percent; and the proportion of leaf fat in the carcasses varied from 3.68 to 4.01 percent in the several lots. In consideration of the small number of pigs involved we cannot with certainty attach importance to these indications of difference in the composition of the carcasses. In our study of the results of this experiment, therefore, we shall restrict our further attention to the development of the skeleton.

Referring to Table II, page 66, it will be noted that we have measured the volumes of six bones, the tibia, fibula and two metatarsals from the hind leg, and the humerus and ulna-radius from the fore-leg. For the comparative purposes of this study the larger bones give the more accurate and significant data, since with these the errors of work are proportionately less. The difficulties encountered in the measurement of the volumes of bones are (1) that evaporation of moisture during the anatomical separation of the bone from connected tissues decreases the thickness and therefore the volume of the cartilaginous structures, (2) that the softer parts of the bones absorb water, and swell, during the weighing in water, or in the determination of volume by displacement of water, (3) that the water in which the bone is immersed in these processes tends to penetrate the bone through its numerous foramina and at the points where tendons have been detached, and (4) the adherence of air to the bone, as it is immersed in water, and the pocketing of air in surface depressions of the bone, introduces further error. On these accounts, and others realized in efforts to obviate these troubles, it is difficult to get satisfactory checks in bone volume determinations. Data relating to the humerus, ulna-radius and tibia are considered to have greater value than those applying to the fibula and the metatarsals.

Comparing the bones of Lot 6 with those of Lots 1 to 5, it will be noted that during the 86 days of this experiment the larger bones increased in volume about one-fourth, and that the bones of Lot 5, which received no mineral supplement, were intermediate in volume as compared with the four lots which received mineral supplements. This observation bears out previous results which show that while some mineral supplements induce a limited increase in the volumes of bones, none of them produce marked increase, while some do not produce any. At the same time there is marked effect upon the density of the bones.

A comparison of these bone volumes seems to show that the calcium carbonate and steamed bone flour tended to produce small bones, as compared with the precipitated bone flour and rock phosphate, and even the unsupplemented basal ration; while the precipitated bone flour and rock phosphate produced larger bones in each case than did the unsupplemented basal ration. Further work will be required to determine whether these differencss are consistent effects of the feeds or are due alone to individuality.

Table III, page 66, sets forth a statement of the ash per cubic centimeter of volume of the bones. In spite of certain irregularities, there is remarkable correspondence in the relative density of these bones in the different lots, the prevailing order of increasing density being Lots 5, 4, 3, 2, 1.

A comparison of Lot 5 with Lots 1 to 4 makes clear the fact that during the 86 days of this experiment there was marked increase in the density of the bones of those pigs which received the mineral supplements, but decidedly less in the case of the rock phosphate than with the other supplements. Recalling the observation made in discussing Table II, that the calcium carbonate and steamed bone flour seemed to produce small bones, it now becomes apparent that these small bones were more dense than those produced under the influence of the other mineral supplements.

Table IV, page 66, exhibits the breaking strength of the bones. This observation is unsatisfactory, from a logical point of view, but has a usefulness as indicating roughly the maximum resistance of the bone to transverse stress applied at the middle. Those conditions which render these data inaccurate are the following: (1) the bones to be compared differ in shape (transverse section); (2) they also vary in ratio of diameter of the bone to thickness of wall; (3) the length of bone as related to diameter is likewise subject to variation; and (4) the shape of the bones renders it impossible to support them at points so related to the length of the same that the breaking strength of one may be consistently compared with that of another. However, in spite of inaccuracies, these data are in a general way concordant with the observations on ash per unit of volume. The two commonly vary together.

Two conditions which may affect the breaking strength are the partial drying and the freezing which takes place during the refrigeration necessary to prevent bacterial decomposition pending the completion of the work preliminary to the breaking tests. These factors have not been investigated.

Inspection of these data shows that there is general agreement as to the comparative breaking strength of the bones in the five lots which received the mineral supplements; thus Lots 1 (calcium carbonate) and 2 (steamed bone flour) were always strongest, followed in each case in the same order by Lots 3 (precipitated bone flour), 5 (basal ration) and 4 (rock phosphate). The striking fact manifest is that the bones of pigs which received rock phosphate were in each case less strong than the bones of the pigs which received no mineral supplement.

Referring to Table III, however, we note that the rock phosphate lot had more ash per cubic centimeter of volume of bones than had the lot which received the unsupplemented basal ration. The bones of the rock phosphate lot, then, were more dense but less strong than the bones of the pigs which received no mineral supplement; and the rock phosphate appears to be decidedly less valuable as a bone food than the other supplements.

Table V, page 67, records individual data on the humerus in each of 30 pigs. These are presented as evidence, especially, of the extent of the variation which prevails within the experimental lots in comparison with the differences between the averages of the data from these several lots. Similar individual data on the other observations are available for inspection.

The measurements of length of these bones vary in about the same way as the volumes, but the differences in transverse diameter are very slight, and do not reflect the differences in volume. Casual observation, then, might not be able to appreciate the considerable differences which exist in the volumes of these bones.

The calcium, magnesium and phosphorus contents of the ash of the bones are stated in Table VI, page 68. The tendency for these constituents to remain constant in ratio, one to another, is strikingly manifest. The percentage of calcium in Lots 1, 2, 3 and 4, but especially in Lot 1 (calcium carbonate) appears significantly higher than in Lot 5 (no supplement); and the magnesium content of Lot 6 (control) is certainly significantly lower than in any of the lots which were carried through the experiment. Since the data for Lot 6 represent pigs which were three and one-half months younger than those for Lots 1 to 5, it may be that an increase in the magnesium content of the bone ash normally accompanies increase in age.

Computation of the proportions of calcium, magnesium and phosphorus in the bone ash of the six lots, reckoning magnesium and phosphorus as percent of calcium (page 65) reveals again the low proportion of magnesium in the ash of the younger pigs of the control lot (No. 6), and also the high proportion of phosphorus to calcium, signifying relatively low proportion of carbonate to phosphate in the bone, in Lots 4, 5 and 6 (rock phosphate, no supplement, and control). The data of the following experiment shows that this low proportion of carbon dioxide to phosphorus is characteristic of relatively weak bone. In this regard the rock phosphate lot (No. 4) is associated with the control and the "no supplement" lots, thus confirming previous evidence that rock phosphate is not a valuable mineral feed.

PROPORTIONS OF CALCIUM, MAGNESIUM AND PHOSPHORUS IN THE BONE ASH

Lots	Calcium	Magnesium	Phosphorus
1	100	2.33	46.93
2	100	2.45	46.77
3	100	2.18	46.85
4	100	2.51	47.56
5	100	2.33	47.39
6	100	2.06	47.20

SUMMARY

1. Thirty growing swine were used in a comparison of mineral supplements to a grain ration, five being killed as a control lot, while the remainder were fed in five lots of five pigs each.

2. To a basal ration of corn, linseed oilmeal and wheat middlings were added in four of the lots, rock phosphate floats, special steamed bone flour, precipitated bone flour and commercial precipitated calcium carbonate. The fifth lot received the basal ration alone.

3. The four mineral supplements were fed in amounts supplying 5 grams of calcium to each pig each day.

4. The general development of the animals was not shown to be influenced by the mineral feeds, but the skeleton was affected in important ways, especially in the ash per unit of volume, the breaking strength and the composition of the ash.

5. In general the precipitated calcium carbonate and steamed bone produced relatively dense and strong bones, while the rock phosphate produced bones but little more dense than and actually not so strong as did the unsupplemented ration. The precipitated bone stood intermediate in these regards.

6. The most pronounced results of this experiment were the demonstration of the inefficiency of rock phosphate floats as a bone food since the pigs receiving this supplement had in their skeletons less ash per unit of volume than any others, while their bones were less strong, even, than those from the lot receiving the unsupplemented ration. Associated with these conditions there was a higher proportion of phosphorus to calcium, implying a lower proportion of carbon dioxide to phosphorus, than in any other lot.

7. It also appears to be significant that the younger pigs of the control lot had less magnesium in the ash of the bones than did the others which were killed after 86 days more of experimental feeding.

TABLE I.—EXPERIMENT III: EFFECTS OF MINERAL SUPPLEMENTS ON THE GROWTH OF SWINE

Lot No.	No. of pigs per lot	Ave. daily feed	Average daily mineral supplement		Ave. initial weight	Ave. final weight	Ave. daily gain in weight	Percent gross dressed to live weight	Percent leaf fat in carcass
		Kilos		*Grams*	*Kilos*	*Kilos*	*Kilos*		
1	5	2.673	Calcium carbonate	7.796	62.72	116.56	0.626	81.35	4.01
2	5	2.650	Steamed bone flour	8.460	62.32	114.12	0.602	80.44	3.74
3	5	2.620	Precipitated bone flour	9.676	62.12	112.68	0.588	79.87	3.76
4	5	2.645	Rock phosphate	8.990	63.12	108.96	0.533	81.69	3.68
5	5	2.673	No mineral		62.44	114.36	0.604	80.17	3.82
6	5	....	Control; killed		62.80	....	....	73.41	....

TABLE II.—EXPERIMENT III: EFFECTS OF MINERAL SUPPLEMENTS ON THE VOLUMES OF THE BONES OF SWINE
Cubic Centimeters, Averages per Lot

Lot No.	Mineral supplements	Humerus	Ulna-radius	Tibia	Fibula	Second meta-tarsal	Third meta-tarsal
1	Calcium carbonate...............	124.36	88.63	82.38	9.14	14.12	14.24
2	Steamed bone flour...............	122.85	86.46	83.37	9.31	14.05	13.61
3	Precipitated bone flour...........	135.58	92.75	89.85	9.44	14.77	14.81
4	Rock phosphate..................	134.01	95.15	90.08	9.19	15.42	15.15
5	No mineral......................	130.43	90.59	85.49	8.99	14.72	14.79
6	Control; killed.....	103.33	72.99	69.19	8.19	11.87	12.47

TABLE III.—EXPERIMENT III: EFFECTS OF MINERAL SUPPLEMENTS ON THE ASH OF THE BONES OF SWINE—Grams of Ash per Cubic Centimeter of Volume—Averages per Lot

Lot No.	Mineral supplements	Humerus	Ulna-radius	Tibia	Fibula	Second metatar-sal	Third metatar-sal
1	Calcium carbonate................	0.5148	0.5753	0.5553	0.7131	0.5165	0.4941
2	Steamed bone flour................	0.5125	0.5677	0.5242	0.6903	0.5381	0.5306
3	Precipitated bone flour............	0.4786	0.5368	0.5104	0.6652	0.4857	0.4822
4	Rock phosphate...................	0.4459	0.4878	0.4751	0.6112	0.4608	0.4451
5	No mineral........................	0.3756	0.4873	0.4909	....	0.4465	0.4423
6	Control; killed..........	0.4645	0.4972	0.4951	0.5706	0.4455	0.4444

TABLE IV.—EXPERIMENT III: EFFECTS OF MINERAL SUPPLEMENTS ON THE BREAKING STRENGTH OF BONES OF SWINE
Pounds, Averages per Lot

Lot No.	Mineral supplements	Humerus	Ulna-radius	Tibia	Fibula	Second metatar-sal	Third metatar-sal
1	Calcium carbonate................	987.7	1158.3	802.3	61.9	457.7	388.1
2	Steamed bone flour................	1017.4	1034.3	748.2	61.1	459.9	396.9
3	Precipitated bone flour............	931.0	833.5	691.4	53.0	404.9	387.7
4	Rock phosphate.......	780.3	784.8	619.6	35.9	337.1	290.9
5	No mineral....................	796.8	811.1	638.4	47.9	363.7	335.1
6	Control; killed..........	821.4	825.6	639.4	53.2	303.8	361.4

TABLE V.—EXPERIMENT III: DATA CONCERNING DEVELOPMENT OF THE HUMERUS

Lot and Pig No.		Length	Shortest transverse diameter	Longest transverse diameter	Mean transverse diameter	Breaking strength	Volume	Ash per cc. volume
		Mm.	*Mm.*	*Mm.*	*Mm.*	*Lbs.*	*c. c.*	*Grams*
I	24	15.7	1.69	2.65	2.17	923.0	126.56	.5093
	33	15.3	1.82	2.65	2.24	1,222.0	122.48	.5654
Calcium carbonate	44	16.5	1.73	2.74	2.24	899.0	138.32	.4760
	52	15.0	1.75	2.69	2.22	896.0	120.87	.5105
	54	14.6	1.80	2.59	2.20	998.5	113.59	.5129
Average		15.42	1.76	2.66	2.21	987.7	124.36	.5148
II	36	15.4	1.81	3.09	2.45	886.0	126.57	.5295
	46	15.7	1.70	2.62	2.16	1,159.5	123.97	.5531
Steamed bone flour	51	15.4	1.63	2.89	2.26	1,067.0	127.49	.4814
	53	15.7	1.66	2.63	2.15	1,004.0	126.25	.4611
	60	14.7	1.75	2.74	2.25	970.5	109.96	.5373
Average		15.38	1.71	2.79	2.25	1,017.4	122.85	.5125
III	26	16.3	1.74	2.65	2.20	859.5	132.27	.5073
	28	17.4	1.73	2.58	2.16	795.5	149.94	.4380
Precipitated bone flour	35	17.4	1.79	2.73	2.26	800.0	157.05	.4439
	49	15.1	1.59	2.72	2.16	904.0	115.48	.4866
	59	15.2	1.90	2.76	2.33	1,296.0	123.16	.5170
Average		16.28	1.75	2.69	2.22	931.0	135.58	.4786
IV	30	16.1	1.78	2.75	2.27	852.5	139.15	.4709
	34	15.5	1.73	2.70	2.22	738.5	122.10	.4395
Rock phosphate floats	38	15.3	1.82	2.67	2.25	928.5	125.51	.4912
	41	17.2	1.90	3.00	2.45	674.0	156.99	.4061
	48	15.6	1.64	2.84	2.24	708.0	126.29	.4217
Average		15.94	1.77	2.79	2.28	780.3	134.01	.4459
V	23	17.4	1.76	2.74	2.25	760.5	163.15	.3648
	40	16.5	1.56	2.73	2.15	692.0	130.91	.4092
No mineral supplement	47	16.3	1.78	2.63	2.21	791.0	136.69	.3097
	50	14.8	1.70	2.66	2.18	930.5	118.95	.3427
	58	14.4	1.68	2.55	2.12	810.0	102.46	.4515
Average		15.88	1.70	2.66	2.18	796.8	130.43	.3756
VI	21	14.0	1.64	2.50	2.07	770.0	107.18	.4621
	22	14.3	1.56	2.45	2.01	877.0	106.24	.4878
Control; killed	42	14.5	1.62	2.37	2.00	810.0	105.03	.4512
	56	13.3	1.53	2.46	2.00	810.0	95.19	.4703
	57	13.8	1.62	2.37	2.00	840.0	103.00	.4510
Average		13.98	1.59	2.43	2.01	821.4	103.33	.4645

TABLE VI.—EXPERIMENT III: EFFECTS OF MINERAL SUPPLEMENTS ON THE COMPOSITION OF THE ASH OF THE BONES OF SWINE—Percent

Lot No., Supplement and Pig No.		Calcium	Magnesium	Phosphorus	Undetermined
Lot I	24	38.429	0.892	17.968	42.711
	33	38.112	0.884	17.696	43.308
Calcium carbonate	44	37.904	0.884	17.896	43.316
	52	37.984	0.884	17.896	43.236
	54	37.880	0.884	17.856	43.380
Average.		38.062	0.886	17.862	43.190
Lot II	36	37.680	0.884	17.784	43.652
	46	37.948	0.884	17.560	43.608
Steamed bone meal	51	37.704	0.900	17.496	43.900
	53	37.948	1.004	17.832	43.216
	60	38.024	0.960	17.872	43.144
Average....................		37.861	0.926	17.709	43.504
Lot III	26	37.992	0.884	17.856	43.268
	28	37.992	0.892	17.768	43.348
Precipitated bone flour	35	37.792	0.744	17.608	43.856
	49	37.732	0.768	17.856	43.644
	59	38.112	0.848	17.744	43.296
Average...........		37.924	0.827	17.766	43.482
Lot IV	30	37.592	1.004	17.896	43.508
	34	37.904	1.004	18.032	43.060
Rock phosphate floats	38	38.112	0.936	17.944	43.008
	41	37.404	0.916	17.896	43.784
	48	37.516	0.864	17.896	43.724
Average.........................		37.706	0.945	17.933	43.417
Lot V	23	37.540	0.884	17.672	43.904
	40	37.272	0.900	17.808	44.020
No mineral supplement	47	37.376	0.848	17.768	44.008
	50	37.420	0.884	17.768	43.928
	58	37.748	0.848	17.768	43.636
Average........................		37.471	0.873	17.757	43.899
Lot VI	21	38.024	0.776	17.856	43.344
	22	37.912	0.768	17.896	43.424
Control; killed	42	37.748	0.776	17.720	43.756
	56	37.732	0.768	17.896	43.604
	57	37.656	0.804	17.872	43.668
Average..................		37.814	0.778	17.848	43.559

4. THE EFFECTS OF MINERAL SUPPLEMENTS ON THE DEVELOPMENT OF SWINE—II

This experiment was conducted between July 26 and November 14, 1919, in the same general manner as the previous study, except that the mineral supplements, instead of being mixed with the feed in amounts such that each furnished the same quantity of calcium, were fed separately, the pigs being allowed to consume them *ad libitum.*

This method of feeding is more likely to prevail in practice than is the mixing of mineral supplements with the grain, since grain is more commonly fed whole than ground, and under conditions such that the mixing of a mineral supplement with the grain would not be practicable.

Such being the situation it becomes a matter of importance to know the relative palatability of the various mineral supplements which are available, and the effects of these supplements in the particular amounts in which pigs choose freely to eat them, the practical usefulness of these feeds being determined by the amounts consumed much more largely than by differences in assimilability.

Forty pigs were used, divided into eight lots of five each. A different mineral supplement was fed to each of seven of these lots, with the same cereal ration, while the eighth was used as a control, and was fed the basal ration alone. The mineral feeds given to the several lots, and the amounts eaten per head per day, were as indicated below:

Lot No.	Mineral Supplement	Supplement Grams	Calcium Grams
1	Rock phosphate floats	12.1	3.723
2	Pulverized limestone	20.1	7.842
3	Special steamed bone	41.3	12.380
4	Whiting	14.0	5.231
5	Precipitated bone flour	21.9	5.389
6	Precipitated calcium carbonate	13.6	5.249
7	Marl	6.8	2.406
8	Basal ration; no mineral supplement	0.0	0.000

Each of these mineral supplements was fed mixed with common salt in the proportion of 97 parts of the calcium compound to 3 parts of salt.

The rock phosphate floats was the ordinary, untreated rock as used for land fertilizing purposes.

The pulverized limestone was an unusually pure product, as ground for application to the soil.

The special steamed bone and precipitated bone preparations were by-products from two methods of gelatine manufacture. Both of these products were very finely divided, the steamed bone being of the fineness ordinarily designated as "floats."

The whiting was of the common commercial grade.

The precipitated calcium carbonate was a by-product from the manufacture of sodium hydrate. It contained free alkali equivalent to 3.59 percent sodium carbonate.

The marl was very finely ground and was in the condition as used as a feed component.

The composition of these supplements is recorded in Table VI, page 83.

As in the previous experiment the basal ration was composed of corn, wheat middlings and linseed oilmeal. At the beginning of the experiment, on July 26, the ration was composed as follows:

Corn meal	300 pounds
Wheat middlings	100 pounds
Linseed oilmeal	100 pounds
Salt	1 pound

From October 3 until the end of the experiment the basal ration was composed as above except that the proportion of corn was increased by one-third.

The pigs used were of mixed breeding with Duroc Jersey and Chester White blood predominating. At the beginning of the experiment, on July 26, they were from 12 to 16 weeks old and weighed 20.87 kilograms or 45.9 pounds each, the average. They were weighed individually, at 2-week intervals, and the experiment was terminated in a slaughter test on December 15. Several individuals which had grown excessively fat, in a way to interfere with breathing, and others which had become crippled on account of the weakness of their bones, were killed before the termination of the experiment, in order that they might not be lost to the investigation. The experiment actually terminated, then, between the dates of November 14 and December 16. This compromise procedure requires that we base conclusions as to gain in weight in relation to feed consumed on the record obtained prior to November 14; and that the breaking strength of the bones be considered with reference to the weight of the animal rather than in the form as directly obtained, since these data for the hogs killed on different dates could not properly be averaged.

The mineral supplements were removed from the self-feeders, to be dried and weighed, at 7-day intervals. They were immediately replaced by fresh material, and each was replenished as occasion required.

During the first 5 weeks of the experiment the pigs had the freedom of dirt lots adjoining the paved lots in which they were fed. During this time they gave very little attention to the mineral supplements. On this account they were then confined to the paved lots, and so remained until the end of the experiment. Within a very few days after being thus confined the pigs in all lots evinced a marked increase of appetite for the mineral supplements. It became evident, therefore, that mineral supplements fed as were these, mixed with 3 percent of salt, were palatable to pigs in close confinement, but not noticeably so to pigs enjoying freedom to root and to forage. For later and much more successful attempts to make mineral feeds palatable to swine see the following paper.

The feeding and slaughter records are set forth in Table I, page 78. The number of individuals is not sufficient to warrant emphasis upon the significance of the differences in these records for the several lots. The data tend rather to sustain the idea that mineral supplements are commonly without marked or certain effect upon the extent or economy of the gain in live weight, though, as will be seen, the effects upon the skeleton were pronounced.

The consumption of mineral supplements, stated in kilograms per week, per lot of five pigs, during 15 weeks, is exhibited in the table on page 86. These figures (see also the tabular data on page 69) show that in palatability the several mineral supplements differed very greatly, and ranked in the following order of decreasing acceptability, from most to least palatable: Steamed bone, precipitated bone, pulverized limestone, whiting, precipitated calcium carbonate, rock phosphate and marl.

The weekly records reveal considerable tendency toward uniform rates of increase and decrease in consumption of the minerals, and definitely consistent differences between most of the lots. The steamed bone was unquestionably the most acceptable and the marl the least so. Both were exceedingly finely ground.

The effects of the mineral supplements on the development of the skeleton are indicated by the data composing Tables II and III, pages 79 and 80. Since the supplements were not fed in equal or equivalent amounts, however, but were allowed at will, and were eaten in greatly differing quantities, the effects of these supplements on the development of the bones were due much more largely to the amounts in which they were eaten than to the differences in the composition of these products.

The results in these two tables, therefore, should be regarded as representing not the specific effects of the several preparations involved but the gross practical effects of feeding these supplements by allowing the animals to run to them at will.

From this point of view the desirable condition in the bodies of the animals is strength of bones in relation to live weight, as set forth in the right-hand columns of these tables. Minor differences must be overlooked, since the breaking strength of a bone, however carefully determined, is, on a number of accounts, a crude measure.

The striking facts revealed by these data are that rock phosphate produced no greater strength of skeleton, in relation to live weight, than did the basal ration (without mineral supplement), while all of the other supplements caused marked and somewhat nearly equal increase in the strength of the bones.

The data in Table IV, page 81, representing the chemical composition of the bones, are averages of closely agreeing triplicates, after the repetition of all divergent or otherwise doubtful figures. At least six estimations of magnesium content were made on each sample; and the figures representing hardness were averages of sixteen estimations each.

Hardness was estimated as depth of penetration of a diamond-pointed punch, one-fiftieth of an inch in diameter, under a pressure of 20 pounds, into a specially prepared transverse section sawed from the narrowest point of the shaft of the bone and ground with sides exactly parallel.

The figures representing hardness are in microns (twenty-five thousandths of an inch, or thousandths of a millimeter). The softer the bone the deeper is the penetration of the punch, and the larger the figure representing hardness, as thus measured.

The apparatus used in these measurements is illustrated on page 73. It consists of a grinding machine, designed for the production of exactly parallel surfaces, and a microdynamometer, both of a very high grade of mechanical accuracy. These machines were invented by Dr. Joseph Head, of Philadelphia, and were specially made for us under his personal direction. The first microdynamometer of this sort was made by Dr. Head for his own use in the study of tooth enamel, and was figured and described in the Journal of the American Medical Association for December 14, 1912, Vol. LIX, pp. 2118-2122. The optical portion of the original

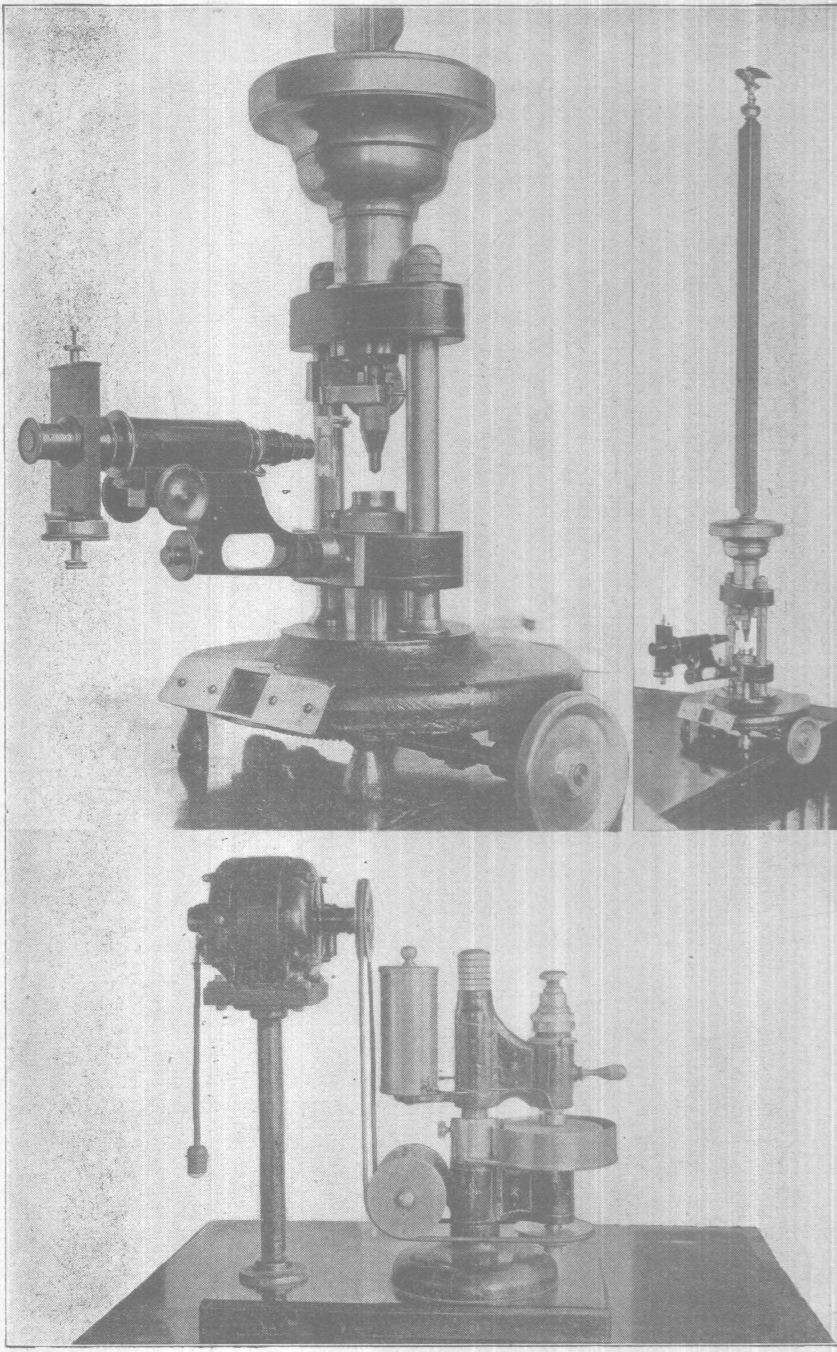

Fig. 1.—Microdynamometer for measuring hardness of bone; and grinding machine for preparation of sections of bone to be tested. (See p. 72)

machine was used in the construction of the second one which was used in this work; otherwise there are numerous improvements in detail of design. Much credit is due Dr. Head for his generous bestowal of time and effort in the oversight of the building of these machines. (See Fig. 1, page 73.)

The figures for moisture and fat vary widely within the lots. Since bones are very refractory materials to sample in the fresh condition it is likely that our figures for moisture are distinctly less accurate than those stated on the fat- and water-free basis. It is perhaps worthy of note, however, that, in the steamed bone lot (No. 3), both moisture and fat were lower, while the ash, as related both to the volume and to the fat- and water-free substance, was higher than in any other lot.

The percentage of calcium, magnesium, phosphorus, carbon dioxide* and ash were characterized by marked similarity in the several experimental lots. There were differences, however, and the question is as to the significance of these differences.

Naturally the bones of the lot receiving no mineral supplement (No. 8) were low in the mineral constituents, other than magnesium, and in ash per cubic centimeter of volume, since lack of mineral substance characterizes poorly-nourished bones.

It is of interest to note the characteristics of the bones of the steamed bone lot (No. 3), since the pigs in this lot consumed so much more bone food than did the others. In this lot we find distinctly the highest percentages of calcium, carbon dioxide and ash, and the lowest magnesium content; and the bones from this lot of pigs were harder than any others. It would seem that these conditions are associated with a well-nourished state of skeletal tissue.

The most critical basis for judgment as to the relative amounts of the mineral constituents of the bones is furnished by the data in Table V, page 82, which are the four principal constituents of the fat- and water-free bone stated in percentage of the sum of the four.

This tabulation shows that the hardest bones (Lot 3, steamed bone) had the lowest magnesium content, in relation to the other mineral constituents; while the softest bones of all (Lot 1, rock phosphate) were characterized by maximum proportions of magnesium and phosphorus, and minimum proportions of calcium and carbon dioxide.

Hard bone appears to differ from soft bone, then, by a partial replacement of magnesium phosphate by calcium carbonate.

*Carbon dioxide was estimated by the method of D. D. Van Slyke, Journ. Biol. Chem. 36 (1918), 351

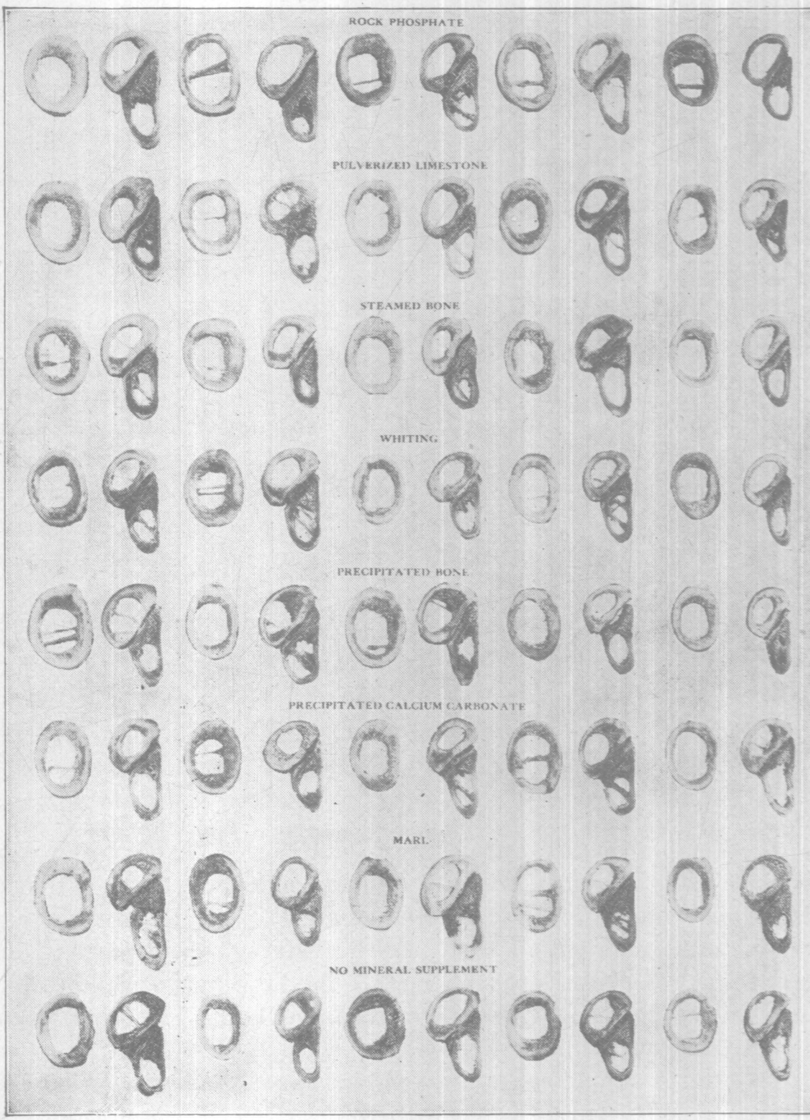

Fig. 2.—Cross section of humerus, and ulna-radius

A significant proportion of constituents of the bones, in relation to acid neutralization and the alkali reserve, are the relative amounts of phosphorus and carbon dioxide.

The amount of carbon dioxide calculated as percent of the amount of phosphorus in the average composition of the several lots is as follows:

Lot	Supplement	Percent CO_2 : P
1	Rock phosphate	23.8
2	Limestone	26.9
3	Steamed bone	28.2
4	Whiting	27.5
5	Precipitated bone	26.6
6	Calcium carbonate	28.3
7	Marl	29.8
8	No mineral	24.8

The proportion of carbon dioxide to phosphorus in the bones of Lots 1 and 8 (rock phosphate, and no mineral) is distinctly lower than in the others. Since little of the rock phosphate was eaten (still less, of course, being assimilated), and since no mineral supplement was eaten by Lot 8, it is probable that the low proportion of carbon dioxide to phosphorus signified withdrawal of carbon dioxide in response to protracted deficiency of potential alkali in the system.

It appears, therefore, that the mineral substance of bone is a mixture of carbonates and phosphates, which is susceptible of modification through the selective withdrawal of carbonate, this carbonate constituting a portion of the so-called alkali reserve of the body.

SUMMARY

1. Forty growing swine, confined in brick-paved lots, were used in a comparison of mineral supplements to a basal ration of corn, wheat middlings and linseed oilmeal. One lot of five pigs received this grain ration alone; the remaining seven received one each of the following: rock phosphate floats, pulverized limestone, special steamed bone, whiting, precipitated bone, precipitated calcium carbonate and marl.

2. These supplements, mixed in each case with 3 percent of common salt, were fed at will, that is, without restriction of amount. Under these circumstances the amounts of each consumed per head per day were, special steamed bone 41.3 grams, precipitated bone flour 21.9 grams, pulverized limestone 20.1 grams, whiting 14 grams, precipitated calcium carbonate 13.6 grams, rock phosphate 12.1 grams, and marl 6.8 grams.

3. The amounts of calcium furnished per head per day by the amounts of these supplements consumed were as follows: special steamed bone 12.380 grams, pulverized limestone 7.842 grams, precipitated bone flour 5.389 grams, precipitated calcium carbonate 5.249 grams, whiting 5.231 grams, rock phosphate floats 3.723 grams, and marl 2.406 grams.

4. Rock phosphate produced no greater strength of skeleton, in relation to live weight, than did the basal ration (without mineral supplement), while all other supplements caused marked and somewhat nearly equal increase in the strength of the bones.

5. Special steamed bone had the effect to produce bones containing less moisture and fat, and more ash, as related both to volume and to fat- and water-free substance, than were produced under the influence of any other supplement. The calcium and carbon dioxide contents and the hardness of the bones excelled all other lots, while the magnesium content was the lowest of all.

6. The bones of pigs raised on a cereal ration, without a mineral supplement, were relatively poor in mineral constituents other than magnesium.

7. The hardest bones (Lot 3, special steamed bone) were characterized by the maximum percent of calcium, carbon dioxide and ash, and minimum magnesium content, in the fat- and water-free bone, and also by minimum magnesium content in the sum of the mineral constituents determined (Ca, Mg, P, CO_2).

8. The softest bones (Lot 1, rock phosphate) were characterized by maximum proportions of magnesium and phosphorus, and minimum proportions of calcium and carbon dioxide, in the sum of the mineral constituents determined.

9. The mineral substance of bone is a mixture of phosphate and carbonate from which carbonate can be selectively withdrawn, apparently as a portion of the so-called alkali reserve of the body.

TABLE I.—EXPERMENT IV: FEEDING AND SLAUGHTER RECORDS
Averages per Pig

Lot number and supplement	Average initial weight	Average final weight*	Average daily gain in weight	Gain per kilo grain eaten	Gross dressed weight	Percent dressed to live weight	Thickness of back-fat		Average daily grain eaten	Leaf-fat	Percent leaf-fat in carcass	Live weight, date of slaughter
							Shoulder	Rump				
	Kg.	*Kg.*	*Kg.*	*Kg.*	*Kg.*		*Mm.*	*Mm.*	*Kg.*	*Kg.*		*Kg.*
1 Rock phosphate	21.1	68.2	0.42	0.275	60.9	77.1	49	35	1.530	2.08	3.4	79.0
2 Limestone	21.2	67.6	0.41	0.271	62.0	78.1	53	37	1.515	2.31	3.7	79.4
3 Steamed bone	20.7	72.0	0.46	0.299	60.4	78.1	52	39	1.541	2.39	4.0	77.3
4 Whiting	20.6	65.2	0.40	0.276	53.8	80.3	48	36	1.451	1.82	3.3	67.0
5 Precipitated bone	20.7	66.9	0.41	0.281	57.2	78.2	48	36	1.458	1.91	3.3	73.1
6 Calcium carbonate	21.0	70.4	0.44	0.286	61.2	78.6	56	37	1.537	2.50	4.1	77.9
7 Marl	21.0	68.2	0.42	0.275	55.6	80.0	54†	37†	1.526	2.06	3.7	69.5
8 No supplement	20.7	68.2	0.42	0.289	53.6	78.5	51‡	34‡	1.451	1.87	3.5	68 [illegible]

*Weight on November 14.
†Four pigs only.
‡Three pigs only.

TABLE II.—EXPERIMENT IV: DATA CONCERNING THE DEVELOPMENT OF THE BONES

The Humerus

Lot No. and supplement	Pig No.	Weight	Volume	Length	Longer diameter of shaft	Shorter diameter of shaft	Breaking strength	Breaking strength ÷ live weight
		Grams	*c. c.*	*Cm.*	*Cm.*	*Cm.*	*Lbs.*	
1 Rock phosphate....	58	91.15	69.53	12.9	1.96	1.34	362.0	3.49
1 Rock phosphate....	91	166.72	131.75	15.3	2.44	1.72	560.5	2.25
1 Rock phosphate....	78	109.22	86.22	13.2	2.20	1.53	554.5	3.08
1 Rock phosphate....	79	144.80	110.95	15.2	2.28	1.57	398.0	2.66
1 Rock phosphate....	87	127.00	99.90	14.3	1.35	1.58	457.5	2 45
Average..........		127.78	99.67	14.2	2.05	1.55	466.5	2.79
2 Limestone..........	66	103.55	81.95	13.2	2.27	1.38	538.0	4.22
2 Limestone..........	96	148.72	106.95	14.6	2.45	1.68	763.5	3.63
2 Limestone..	79	125.69	99.18	14.8	2.21	1.53	511.5	2.82
2 Limestone..........	99	131.92	100.92	14.3	2.11	1.45	549.0	3.67
2 Limestone..........	75	160.55	126.01	15.9	2.15	1.60	594.5	2.90
Average..........		134.09	103.00	14.6	2.24	1.53	591.3	3.45
3 Steamed bone.......	74	100.69	75.12	13.4	1.98	1.43	578.0	4.16
3 Steamed bone.......	85	140.02	104.67	14.9	2.27	1.68	718.5	3.55
3 Steamed bone.......	53	104.90	78.70	13.0	2.28	1.54	504.0	2.86
3 Steamed bone.......	77	113.47	81.67	13.5	2.16	1 62	690.0	3.82
3 Steamed bone......	93	96.97	75.90	13.2	2.15	1.46	514.0	3.38
Average.		111.21	83.21	13.6	2.17	1.55	600.9	3.55
4 Whiting............	52	77.03	60.83	11.8	2.01	1.28	459.0	4.35
4 Whiting............	55	127.80	98.68	13.5	2.28	1.55	670.0	3.98
4 Whiting............	81	131.30	101.73	15.0	2.21	1.57	585.0	3.07
4 Whiting............	61	93.72	72.37	13.1	2.04	1.40	516.0	3.50
4 Whiting............	100	90 48	70.38	12.8	2.04	1.35	460.5	3.70
Average..........		104.07	80.80	13.2	2.12	1.43	538.1	3.72
5 Precipitated bone..	63	80.97	62.27	12.2	1.97	1.34	480.5	3.93
5 Precipitated bone..	70	108.50	86.38	13.7	2.16	1.46	468.5	2.72
5 Precipitated bone..	74	135.51	102.91	14.0	2.45	1.75	629.0	3.41
5 Precipitated bone..	82	123.80	93.35	13.4	2.37	1.57	696.5	4.07
5 Precipitated bone..	90	105 71	81.09	14.1	2.06	1.42	467.5	3.04
Average..........		110.90	85.20	13.5	2.20	1.51	548.4	3.43
6 Calcium carbonate	89	116.53	93.36	13.4	2.12	1.40	493.0	3.25
6 Calcium carbonate	83	107.81	82.41	13.3	2.09	1.49	644.0	3.57
6 Calcium carbonate	76	122.47	92.85	14.0	2.19	1.45	687.0	3.96
6 Calcium carbonate	68	110.32	86.07	14.2	2.16	1.43	544.5	3.34
6 Calcium carbonate	92	132.02	101.88	14.6	2.17	1.53	610.5	3.25
Average..........		117.83	91.31	13.9	2.15	1.46	595.8	3.47
7 Marl...............	73	79.12	63.86	12.0	1.98	1.30	462.0	4.41
7 Marl...............	91	129.82	104.48	13.8	2.25	1.45	598.5	3.19
7 Marl...............	80	110.75	88.73	13.4	2.08	1.47	459.0	3.27
7 Marl...............	97	113.60	89.90	13.4	2.20	1.60	544.0	3.18
7 Marl...............	66	117.97	90.84	12.8	2.24	1.47	661.0	4.10
Average..........		110.25	87.56	13.1	2.15	1.46	544.9	3.63
8 No supplement.....	95	84.22	68.12	12.6	2.02	1.39	422.5	3.01
8 No supplement.....	94	98.17	79.67	12.5	2.07	1.53	455.0	3.18
8 No supplement.....	56	110.82	87.12	13.6	2.18	1.58	495.0	2.80
8 No suyplement.....	67	104.41	81.61	13.7	2.05	1.35	394.5	2.31
8 No supplement.....	54	89.00	72.50	13.2	1.90	1 33	408.0	3.38
Average..........		97.32	77.80	13.1	2.04	1.44	435.0	2.94

TABLE III.—EXPERIMENT IV: DATA CONCERNING THE DEVELOPMENT OF THE BONES

The Tibia

Lot No. and supplement	Pig No.	Weight	Volume	Length	Longer diameter of shaft	Shorter diameter of shaft	Breaking strength	Breaking strength ÷live weight
		Grams	*c. c.*	*Cm.*	*Cm.*	*Cm.*	*Lbs.*	
1 Rock phosphate....	58	64.16	48.48	14.0	1.87	1.21	252.5	2.43
1 Rock phosphate....	91	108.54	82.39	16.0	2.01	1.33	348.0	1.40
1 Rock phosphate....	78	76.66	58.24	13.5	2.00	1.37	392.0	2.18
1 Rock phosphate....	79	107.51	79.91	16.2	2.12	1.43	352.2	2.36
1 Rock phosphate....	87	87.75	67.05	14.4	2.23	1.30	315.0	1.69
Average..........	....	88.92	67.21	14.82	2.05	1.33	332.0	2.01
2 Limestone..........	66	71.69	54.90	14.4	1.80	1.17	311.0	2 44
2 Limestone..........	96	101.50	71.40	15.6	2.15	1.39	522.0	2.48
2 Limestone..........	79	85.63	67.20	14.8	2.10	1.35	358.5	1.98
2 Limestone..........	99	89.35	66.85	15.2	1.77	1.33	390.0	2.61
2 Limestone..........	75	109.90	83.41	16.3	1.91	1.37	441.0	2 15
Average..........	....	91.61	68.75	15.5	1.95	1.32	404.5	2.33
3 Steamed bone......	74	67.70	50.33	13.9	1.88	1.30	349.0	2.51
3 S eamed bone......	85	100.72	73.39	15.5	2.18	1.45	455.5	2.25
3 Steamed bone......	53	73.72	54.05	13.4	1.99	1.33	411.0	2.34
3 Steamed bone......	77	72.36	50.90	13.8	1.92	1.30	488.5	2.70
3 Steamed bone......	93	77.47	57.90	13.8	1.89	1.35	440.0	2.89
Average..........	... .	78.39	57.31	14.1	1.97	1.35	428.8	2.54
Whiting............	52	52.73	40.09	12.5	1.77	1.12	313.5	2.97
4 Whiting............	55	81.91	61.91	14.0	1.96	1.37	457.0	2.71
4 Whiting............	81	87.17	65.54	15.5	2.00	1.36	383.0	2.01
4 Whiting............	61	67.68	50.78	13.5	1.87	1.34	375.0	2.54
4 Whiting............	100	63.19	48.64	13.8	1.67	1.25	305.0	2.45
Average..........	. .....	70.54	53.39	13.9	1.85	1.29	366.7	2.54
5 Precipitated bone..	63	55.70	39.63	13.0	1.65	1.13	383.0	3.13
5 Precipitated bone..	70	80.10	61.48	14.1	2.40	1.30	365.5	2.12
5 Precipitated bone..	74	89.87	66.83	15.1	2.13	1.33	429.0	2.33
5 Precipitated bone..	82	85.37	63.22	13.8	2.14	1.34	472.0	2.76
5 Precipitated bone..	90	69.72	52.20	13.7	1.73	1.18	292.0	1.90
Average.	....	76.15	56.67	13.9	2.01	1.26	388.3	2.45
6 Calcium carbonate.	89	82.89	63.19	14.1	1.93	1.38	409.5	2.70
6 Calcium carbonate.	83	80.22	58.87	13.8	1.99	1.30	494.0	2.74
6 Calcium carbonate.	76	86.34	63.17	14.7	1.96	1.28	474.5	2.73
6 Calcium carbonate.	68	74.70	55.20	13.9	1.98	1.32	423.5	2.59
6 Calcium carbonate.	92	93.82	70.55	15.6	1.94	1.37	406.0	2.16
Average..........	....	83.59	62.20	14.4	1.96	1.33	441.5	2.58
7 Marl................	73	51.00	40.30	12.1	1.77	1.19	261.5	2.50
7 Marl	91	96.12	73.40	14.8	1.86	1.41	438.0	2.34
7 Marl................	80	73.40	57.48	13.5	1.97	1.27	315.0	2.24
7 Marl................	97	83.47	64.39	14.1	2.19	1.33	368.0	2.15
7 Marl................	66	68.42	52.20	13.6	1.83	1.27	346.0	2.15
Average..........	....	74.48	57.55	13.6	1.92	1.29	345.7	2 28
8 No supplement.....	95	59.82	48.12	12.6	1.83	1.26	304.0	2.17
8 No supplement.....	94	68.85	55.05	13.5	1.87	1.28	313.5	2.19
8 No supplement.....	56	77.37	60.04	14 2	1.97	1.38	341.0	1.93
8 No supplement.....	67	70.19	55.59	15.1	1.82	1.20	241.0	1.41
8 No supplement.....	54	61.63	49.94	13.9	1.77	1.22	245.0	2.03
Average..........	....	67.57	53.75	13.9	1.85	1.27	288.9	1.95

TABLE IV.—EXPERIMENT IV: CHEMICAL COMPOSITION AND HARDNESS OF THE BONES

The Tibia

Lot No. and supplements	Pig No.	Fresh basis		Fat- and water-free basis					Ash per c. c. volume	Hardness, by penetration
		Moisture	Ether extract	Calcium	Magnesium	Phosphorus	Carbon dioxide	Ash		
		Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Grams*	*Microns*
1 Rock phosphate	58	23.6976	19.8984	22.8065	0.7237	11.9805	2.6492	61.2802	0.8110	84.5
	91	29.5776	20.2240	21.5537	0.6044	11.2726	2.8085	58.0534	0.7648	65.5
	78	24.0887	26.1109	22.0555	0.6042	11.5141	2.5387	58.4236	0.7690	65.4
	79	24.8801	21.0708	22.1437	0.6690	11.4699	2.8324	59.1746	0.7961	73.2
	87	24.1868	25.5559	22.1585	0.6396	11.3869	2.8886	59.1287	0.7747	69.8
Average......	......	25.2862	22.5720	22.1436	0.6482	11.5248	2.7434	59.2123	0.7831	71.7
2 Limestone	66	30.7652	17.6598	21.6754	0.5510	11.0972	2.7788	57.1555	0.7463	53.2
	96	37.4512	11.5867	22.1558	0.5416	11.2297	2.9225	58.3923	0.8301	59.3
	79	24.0719	38.8010	22.5787	0.5841	11.3482	3.2168	59.7911	0.7619	52.9
	99	23.9316	21.9972	21.7353	0.5223	10.8199	3.0551	57.8921	0.7738	63.1
	75	27.6784	21.1654	21.5363	0.5272	10.8106	2.9108	57.5399	0.7581	54.2
Average......	......	28.7796	22.2410	21.9363	0.5452	11.0611	2.9768	58.1322	0.7740	56.3
3 Steamed bone	85	23.0093	22.0629	23.1643	0.5173	11.3677	3.3612	60.5832	0.8314	44.8
	74	17.8128	20.7931	22.8518	0.5651	11.4475	3.2973	60.6178	0.8154	38.4
	77	21.5421	18.2994	23.1957	0.5476	11.4787	3.1213	61.1049	0.8687	44.6
	53	15.3556	26.0210	23.1658	0.5277	11.4504	3.1309	60.7675	0.8288	44.3
	93	31.6726	13.5467	22.2388	0.4853	11.0631	3.1171	58.8668	0.7876	49.0
Average....	......	21.8724	20.1446	22.9233	0.5286	11.3615	3.2056	60.3880	0.8264	44.2
4 Whiting	55	20.6446	27.3064	22.9280	0.5608	11.2328	3.2984	60.3729	0.7987	48.8
	81	25.8265	22.7122	22.9151	0.5664	11.2630	3.1422	60.9068	0.8101	45.7
	52	27.1059	20.8159	22.1170	0.5377	10.7764	2.7427	58.2174	0.7657	57.9
	100	27.0982	26.4049	21.8820	0.5587	10.9129	2.8255	57.5803	0.7480	47.7
	61	19.3933	23.9572	21.5660	0.5027	10.5321	3.0289	57.0108	0.7598	57.9
Average......	......	24.0138	24.2393	22.2816	0.5453	10.9434	3.0075	58.8176	0.7766	51.6
5 Precipitated bone	70	22.6307	29.4599	21.9187	0.5424	10.5219	2.7971	58.0432	0.7562	52.5
	82	24.1853	22.1239	23.0254	0.5414	11.3036	3.1373	60.5668	0.8179	57.2
	74	23.9979	21.2010	22.1412	0.5378	11.0272	3.0150	58.8810	0.7918	53.2
	90	28.9486	18.2280	22.1934	0.5504	11.1952	2.7539	59.1645	0.7902	55.5
	63	23.5522	17.1556	23.1021	0.5919	11.0799	2.9757	61.2461	0.8608	44.7
Average......	......	24.6629	21.6337	22.4762	0.5528	11.0256	2.9358	59.5803	0.8034	52.6
6 Calcium carbonate	92	24.1473	22.9681	22.2358	0.5474	10.9913	3.3606	59.9004	0.7966	66.5
	83	23.0165	21.6289	22.7831	0.5763	10.8211	3.0679	60.1884	0.8202	60.3
	68	16.6425	27.1956	22.7210	0.5990	10.9049	3.1929	59.6195	0.8068	55.9
	76	23.2059	22.0868	22.6252	0.6010	10.9885	2.8110	60.1546	0.8222	62.8
	89	26.0152	23.2812	22.3116	0.5605	10.6792	2.9725	58.9613	0.7734	71.6
Average......	......	22.6055	23.4321	22.5353	0.5768	10.8770	3.0809	59.7668	0.8038	63.4
7 Marl	91	24.0627	27.3484	22.1877	0.6034	10.6873	3.2179	58.8972	0.7748	66.2
	80	26.4498	29.0056	22.2594	0.5471	10.8213	3.2675	59.5879	0.7609	53.1
	97	28.2748	22.3816	21.7620	0.5167	10.5294	3.1615	57.6952	0.7479	52.1
	66	23.3212	21.9436	22.4019	0.5457	10.8634	3.0217	59.7617	0.7833	67.4
	73	24.7102	28.5659	21.9738	0.5674	10.6756	3.2862	58.5859	0.7414	54.8
Average......	......	25.3637	25.8490	22.1169	0.5561	10.7154	3.1910	58.9056	0.7617	58.7
8 No supplement	56	23.5142	29.1168	22.6524	0.5296	11.0301	3.0295	59.8594	0.7714	45.4
	94	24.0241	33.1345	21.7586	0.6095	10.5692	2.9423	57.5729	0.7201	49.5
	67	27.7398	27.0887	21.2205	0.5628	10.4621	2.3192	56.6329	0.7151	67.9
	95	28.6175	26.0698	21.9724	0.5575	10.5800	2.5320	57.8667	0.7194	50.5
	54	24.4338	36.7499	20.7102	0.5508	11.0101	2.4655	55.4805	0.6847	52.3
Average......	......	25.6659	30.4319	21.6628	0.5620	10.7303	2.6577	57.4825	0.7221	53.1

TABLE V.—EXPERIMENT IV: THE FOUR PRINCIPAL MINERAL CONSTITUENTS OF THE BONE, IN PERCENTS OF THE TOTAL OF THESE CONSTITUENTS IN THE FAT- AND WATER-FREE BONE

Lot No. and supplement	Pig No.	Calcium	Magnesium	Phosphorus	Carbon dioxide
		Percent	*Percent*	*Percent*	*Percent*
1 Rock phosphate	58 91 78 79 87	59.766 59.476 60.076 59.662 59.769	1.896 1.668 1.664 1.803 1.725	31.396 31.106 31.363 30.904 30.714	6.942 7.750 6.915 7.631 7.792
Average.......... ...	....	59.751	1.749	31.098	7.403
2 Limestone	66 96 79 99 75	60.039 60.125 59.846 60.154 60.183	1.526 1.470 1.548 1.446 1.473	30.738 30.474 30.079 29.945 30.210	7.697 7.931 8.526 8.455 8.134
Average..................	....	60.067	1.493	30.288	8.151
3 Steamed bone	85 74 77 53 93	60.307 59.882 60.495 60.525 60.261	1.347 1.481 1.428 1.379 1.315	29.595 29.997 29.937 29.916 29.978	8.751 8.640 8.140 8.180 8.446
Average.	....	60.294	1.390	29.884	8.432
4 Whiting	55 81 52 100 61	60.305 60.483 61.141 60.482 60.528	1.475 1.495 1.486 1.544 1.411	29.544 29.728 29.791 30.164 29.560	8.675 8.294 7.582 7.810 8.501
Average......	....	60 584	1.483	29.755	8.177
5 Precipitated bone	70 82 74 90 63	61.259 60.581 60.295 60.484 61.198	1.516 1.424 1.465 1.500 1.568	29.407 29.740 30.029 30.510 29.351	7.817 8.254 8.211 7.505 7.883
Average....................	....	60.762	1.494	29.807	7.937
6 Calcium carbonate	92 83 68 76 89	59.878 61.165 60.722 61.107 61.088	1.474 1.547 1.601 1.623 1.535	29.598 29.051 29.144 29.678 29.239	9.050 8.236 8.533 7.592 8.139
Average..................	....	60.791	1.556	29.342	8.311
7 Marl	91 80 97 66 73	60.463 60.331 60.501 60.821 60.197	1.644 1.483 1.436 1.482 1.554	29.124 29.330 29.273 29.494 29.246	8.769 8.856 8.789 8.204 9.003
Average....................	....	60.463	1.520	29.294	8.723
8 No supplement	56 94 67 95 54	60.826 60.643 61.394 61.647 59.621	1.422 1.699 1.628 1.564 1.586	29.618 29.457 30.268 29.684 31.696	8.135 8.200 6.710 7.104 7.098
Average.............	....	60.829	1.578	30.130	7.463

TABLE VI.—EXPERIMENT IV: THE MORE IMPORTANT CONSTITUENTS OF THE MINERAL SUPPLEMENTS

Supplement	Calcium	Magnesium	Phosphorus	Silicon
	Percent	*Percent*	*Percent*	*Percent*
Rock phosphate floats	30.705	0.645	12.830	4.494
Pulverized limestone	38.975	0.776	0.006	0.136
Steamed bone	29.940	0.666	13.853	0.172
Whiting	37.275	0.481	0.025	0.751
Precipitated bone	24.600	0.295	16.715	0.099
Precipitated calcium carbonate	38.665	0.765	0.006	0.470
Marl	35.130	1.966	0.007	2.133

5. THE PALATABILITY OF MINERAL SALT PREPARATIONS TO SWINE, CATTLE AND HORSES

In considering the feeding of mineral supplements to farm animals we should bear in mind the fact that in practice such preparations will most commonly be fed, at least to cattle and swine, separate from the remainder of the ration, and by allowing the animals to eat them at will. The likes and dislikes of animals with regard to the various preparations available, therefore, become matters of importance.

In view of the facts as to the mineral requirements of animals the provision of mineral supplements, in addition to common salt, becomes essentially one of supplying calcium either as the phosphate or as the carbonate.

In an effort, then, to gain an understanding of the preferences of animals for such materials the following tests were conducted. In weighing the evidence as presented we would suggest that it would be expecting overmuch of animal nature to assume the existence of a correct and consistent basis for all preferences exhibited. We would not expect the animal's appetite to be an exact expression of nutritive requirements; in fact, it is our belief that the idea of an animal's possessing ability to balance its own ration has been over-emphasized of late.

Also it seems to us desirable to caution the reader against misinterpretation of our results through a wrong attitude toward the relative amounts of the minerals consumed, since a slight preference of one preparation to another may result in the first choice alone being eaten, while the relative acceptability of the two would be most accurately expressed by the consumption of almost the same amounts of each. Our figures denote preference, but should not be considered as numerical expressions of relative acceptability. In a given instance a group of animals may eat ten times as much of one mineral supplement as of another, which signifies not that they would eat ten times as much of the one if the two were offered at different times, but only that the one is perferred to the other. In the selection of a mineral supplement, for practical purposes, then, we may choose one from a group of several which the animals eat readily, but, in view of other considerations of importance, perhaps not the one for which they have the greatest liking.

By way of explanation of the terminology used in the following tables we call attention to the facts that the "special" steamed bone was, as in the preceding experiments, a by-product of gelatine manufacture, while the "soluble bone" preparations were made from this steamed bone by slight acidulation, the objects attained by this treatment being an increase in the palatability of the bone, and in the solubility of its phosphorus. As indicating the condition of the phosphorus of these preparations the following data are submitted, the figures for phosphorus being in terms of P_2O_5:

	Special steamed bone	Soluble bone No. 1	Soluble bone No. 2	Soluble bone No. 3	Soluble bone No. 4
Moisture	5.84	4.75	11.37	13.31	10.83
Total phosphorus	33.85	34.25	32.50	30.65	27.90
Citrate-insoluble	17 60	16.25	13.30	9.25	5.10
Free acid	0.00	0.00	0.00	0.00	0.00

EXPERIMENTS WITH SWINE

Previous to the tests here reported we had conducted an extensive series of similar studies, with precipitated bone, steamed bone, calcium carbonate and various other substances; the results from these earlier tests, however, were not characterized by satisfactory interagreement. The numerical data are open to inspection but are not included in this report. In all of these tests, the animals were given the choice of four mineral supplements, placed in a row, in self-feeders. As a result of later experience it is our judgment that the offering of four supplements together presented too complicated a problem for consistent solution by a pig. In later work in which the pigs had the choice of only two preparations the results were very much more consistent and satisfactory.

From the earlier work we have gleaned a few observations, however, which seem to be warranted, in spite of a general lack of satisfactory agreement in the results, and these are included in the conclusions of this paper.

The subjects of the tests here reported were young, growing swine. They were fed by hand, in the usual way, on rations of ground feed. In Test No. 1 the pigs were confined to brick-paved lots. In all other tests the pigs were fed in these same lots but in addition had the run of dirt lots adjoining. The mineral supplements were in all cases self-fed; that is, they were consumed at will. They were kept before the animals in boxes protected from the weather.

Test No. 1, July 26 to November 28, 1919

Ration, corn, linseed oilmeal and wheat middlings; mineral supplements self-fed, one to each lot of five pigs, mixed, in all cases with 3 percent of common salt; average initial weight of pigs 46 pounds; average final weight of pigs 161 pounds.

MINERAL SUPPLEMENTS EATEN PER LOT OF FIVE PIGS PER WEEK—Kilograms

Week No.	Rock phosphate	Pulverized limestone	Special steamed bone	Whiting	Precipitated bone	Precipitated calcium carbonate	Marl
1	0.000	0.100	0.455	0.150	0.285	0.000	0.300
2	0.249	0.276	0.622	0.188	0.274	0.015	0.273
3	0.165	0.095	0.375	0.280	0.140	0.000	0.155
4	0.067	0.052	0.387	0.188	0.130	0.000	0.087
5	0.080	0.023	0.315	0.172	0.070	0.000	0.035
6	0.400	0.432	0.774	0.581	0.550	0.070	0.345
7	0.772	0.880	0.714	0.630	0.527	0.259	0.370
8	0.824	0.980	1.807	0.604	0.973	0.734	0.328
9	0.622	1.120	2.382	0.592	1.130	1.008	0.227
10	0.550	1.122	2.430	0.477	0.896	1.008	0.300
11	0.524	1.016	2.335	0.913	1.150	0.685	0.158
12	0.583	1.292	2.350	0.965	1.844	1.013	0.277
13	0.528	1.210	1.530	0.668	1.254	0.936	0.352
14	0.487	0.960	2.673	0.460	1.045	0.751	0.142
15	0.515	1.005	2.560	0.500	1.233	0.648	0.246
Total	6.366	10.563	21.709	7.368	11.501	7.127	3.595

Test No. 2, May 15 to 22, 1920

Comparison of special steamed bone and soluble bone preparations; basal ration, corn and linseed oilmeal.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per head per day
1	5	76.5	Steamed bone, 22; Soluble bone No. 1—56
2	5	78.0	Steamed bone, 55; Soluble bone No. 2—23
3	11	40.7	Steamed bone, 30; Soluble bone No. 3—24
4	5	75.8	Steamed bone, 35; Soluble bone No. 4—39

Test No. 3, May 22 to 29, 1920

Comparison of special steamed bone and soluble bone preparations; basal ration, corn and linseed oilmeal.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day: Steamed bone		Soluble bone
1	5	73.0	14.3	No. 1	16.3
2	5	79.3	3.5	No. 1	29.4
3	5	70.4	2.6	No. 2	6.0
4	5	81.0	14.3	No. 2	12.9
5	5	49.2	6.1	No. 3	9.4
6	5	65.8	16.1	No. 3	36.0
7	5	79.1	3.7	No. 4	25.9
8	5	41.7	2.1	No. 4	7.5

Test No. 4, May 26 to 27, 1920

Comparison of tankage and fenugreek, as flavoring substances, mixed with special steamed bone; basal ration, corn and linseed oilmeal.

No. of pigs	Ave. weight of pigs Kg.	Grams eaten per pig per day	
5	45	Steamed bone, 100 percent	37
		Steamed bone, tankage, 90:10	311
		Steamed bone, fenugreek, 90:10	0

Test No. 5, May 27 to June 3, 1920

Comparison of tankage and anise seed, as flavoring substances, mixed with special steamed bone; basal ration, corn and linseed oilmeal.

No. of pigs	Ave. weight of pigs Kg.	Grams eaten per pig per day	
5	47	Steamed bone, tankage, 90:10	38.6
		Steamed bone, anise, 90:10	1.2

Test No. 6, May 29 to June 3, 1920

Comparison of flavoring substances, mixed with special steamed bone; basal ration, corn and linseed oilmeal.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day	
1	5	78.0	Steamed bone, tankage, 10:1	27.4
			Steamed bone	0.8
2	5	70.3	Steamed bone, tankage, 10:1	14.4
			Steamed bone	0.0
3	5	75.5	Steamed bone, tankage, 10:1	12.0
			Steamed bone, anise, 10:1	0.6
4	5	82.9	Steamed bone, tankage, 10:1	27.0
			Steamed bone, caraway, 10:1	0.0
5	5	54.0	Steamed bone, tankage, 10:1	45.3
			Steamed bone, ginger, 10:1	0.4
6	5	46.1	Steamed bone, tankage, 10:1	18.2
			Steamed bone, fennel, 10:1	0.8
7	5	84.7	Steamed bone, tankage, 10:1	74.4
			Steamed bone, coriander, 10:1	22.2
8	5	83.2	Steamed bone, tankage, 10:1	48.5
			Steamed bone, fenugreek, 10:1	2.0

Test No. 7, June 3 to 8, 1920

Comparison of flavoring substances, mixed with special steamed bone and soluble bone; basal ration, corn and linseed oilmeal.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day	
1	5	80.9	Soluble bone No. 3, tankage, 9:1	17.8
			Steamed bone, tankage, 9:1	1.8
2	5	73.8	Soluble bone No. 3, tankage, 9:1	16.6
			Steamed bone, tankage, 9:1	3.1
3	5	78.9	Soluble bone No. 3, tankage, 9:1	14.4
			Soluble bone No. 3, anise, 9:1	0.2
4	5	86.5	Soluble bone No. 3, tankage, 9:1	35.8
			Soluble bone No. 3, caraway, 9:1	0.6
5	5	56.1	Soluble bone No. 3, tankage, 9:1	31.0
			Soluble bone No. 3, ginger, 9:1	0.8
6	5	47.9	Soluble bone No. 3, tankage, 9:1	23.2
			Soluble bone No. 3, charcoal, 9:1	7.2
7	5	88.1	Soluble bone No. 3, tankage, 9:1	47.8
			Soluble bone No. 3, coriander, 9:1	13.8
8	5	86.6	Soluble bone No. 3, tankage, 9:1	62.5
			Soluble bone No. 3, fenugreek, 9:1	2.2
9	5	....	Soluble bone No. 3, tankage, 9:1	31.6
			Soluble bone No. 3, alfalfa, 9:1	3.7

Test No. 8, June 8 to 12, 1920

Comparison of special steamed bone and soluble bone preparations; basal ration, corn, linseed oilmeal and tankage.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day	
1	5	84.4	Soluble bone No. 3, tankage, 9:1	1.2
			Steamed bone, tankage, 9:1	1.0
2	5	82.4	Soluble bone No. 3, tankage, 9:1	1.4
			Steamed bone, tankage, 9:1	1.0
3	5	90.0	Soluble bone No. 3, tankage, 9:1	9.8
			Soluble bone No. 1, tankage, 9:1	1.2
4	5	57.2	Soluble bone No. 3, tankage, 9:1	7.8
			Soluble bone No. 1, tankage, 9:1	1.8
5	5	77.8	Soluble bone No. 3, tankage, 9:1	1.0
			Soluble bone No. 2, tankage, 9:1	1.6
6	5	49.5	Soluble bone No. 3, tankage, 9:1	1.0
			Soluble bone No. 2, tankage, 9:1	2.4
7	5	91.0	Soluble bone No. 3, tankage, 9:1	7.2
			Soluble bone No. 4, tankage, 9:1	40.8
8	5	90.2	Soluble bone No. 3, tankage, 9:1	11.4
			Soluble bone No. 4, tankage, 9:1	18.8

Test No. 9, June 12 to 16, 1920

Comparison of special steamed bone and soluble bone preparations; basal ration, corn, linseed oilmeal and tankage.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day	
1	5	88.3	Soluble bone No. 3, tankage, 9:1	0.0
			Steamed bone, tankage, 9:1	0.0
2	5	87.8	Soluble bone No. 3, tankage, 9:1	0.0
			Steamed bone, tankage, 9:1	0.0
3	5	94.2	Soluble bone No. 3, tankage, 9:1	8.9
			Soluble bone No. 1, tankage, 9:1	0.0
4	5	59.7	Soluble bone No. 3, tankage, 9:1	0.0
			Soluble bone No. 1, tankage, 9:1	0.0
5	5	81.8	Soluble bone No. 3, tankage, 9:1	0.0
			Soluble bone No. 2, tankage, 9:1	0.2
6	5	51.8	Soluble bone No. 3, tankage, 9:1	0.0
			Soluble bone No. 2, tankage, 9:1	0.6
7	5	94.6	Soluble bone No. 3, tankage, 9:1	1.5
			Soluble bone No. 4, tankage, 9:1	27.0
8	5	94.4	Soluble bone No. 3, tankage, 9:1	3.6
			Soluble bone No. 4, tankage, 9:1	21.0

Test No. 10, July 13 to 19, 1920

Comparison of tankage and dried blood, as flavoring substances, mixed with soluble bone; basal ration, corn and tankage.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day	
1	5	72.2	Soluble bone No. 4, tankage, 10:1	54.3
			Soluble bone No. 4, dried blood, 10:1	10.8
2	5	73.2	Soluble bone No. 4, tankage, 10:1	38.6
			Soluble bone No. 4, dried blood, 10:1	24.7
3	5	81.2	Soluble bone No. 4, tankage, 10:1	47.8
			Soluble bone No. 4, dried blood, 10:1	28.8

Test No. 11, July 23 to 29, 1920

Comparison of tankage and dried blood, as flavoring substances, mixed with soluble bone; basal ration, corn and tankage.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day	
1	5	73.9	Soluble bone No. 4, tankage, 9:1	40.0
			Soluble bone No. 4, dried blood, 9:1	7.7
2	5	76.0	Soluble bone No. 4, tankage, 9:1	70.0
			Soluble bone No. 4, dried blood, 9:1	31.7
3	5	84.0	Soluble bone No. 4, tankage, 9:1	69.3
			Soluble bone No. 4, dried blood, 9:1	53.7

Test No. 12, July 23 to 29, 1920

Comparison of special steamed bone and soluble bone; basal ration, corn, wheat middlings and skimmilk.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	6	26.4	Steamed bone, tankage, 9:1 .... 3.1
			Soluble bone No. 4, tankage, 9:1..........29.0
2	6	21.5	Steamed bone, tankage, 9:1 .... 2.5
			Soluble bone No. 4, tankage, 9:1..........10.3
3	6	25.5	Steamed bone, tankage, 9:1 .... 4.3
			Soluble bone No. 4, tankage, 9:1.......... 7.1
4	6	23.6	Steamed bone, tankage, 9:1 .... 3.2
			Soluble bone No. 4, tankage, 9:1..........12 0

Test No. 13, August 10 to 21, 1920

Comparison of special steamed bone and soluble bone; basal ration, corn, wheat middlings and skimmilk.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	6	34.3	Steamed bone, tankage, 9:1 ....16.1
			Soluble bone No. 4, tankage, 9:1..........26.0
2	6	29.2	Steamed bone, tankage, 9:1 ....16.1
			Soluble bone No. 4, tankage, 9:1..........19.3
3	6	34.1	Steamed bone, tankage, 9:1 ....18.0
			Soluble bone No. 4, tankage, 9:1..........19.6
4	6	30.6	Steamed bone, tankage, 9:1 ....16.7
			Soluble bone No. 4, tankage, 9:1..........24.7

Test No. 14, July 31 to August 5, 1920

Comparison of packer's steamed bone and soluble bone; basal ration, corn and tankage.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	5	77.4	Packer's steamed bone 26.5
			Soluble bone No. 4 .... 1.4
2	5	79.2	Packer's steamed bone 26.2
			Soluble bone No. 4 ....20.6
3	5	87.4	Packer's steamed bone 49.4
			Soluble bone No. 4 .... 8.2

Test No. 15, July 21 to August 10, 1920

Comparison of packer's steamed bone (alone) with soluble bone and tankage; basal ration, corn, wheat middlings and skimmilk.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	6	29.6	Packer's steamed bone 8.5
			Soluble bone No. 4, tankage, 9:1..........24.4
2	6	25.2	Packer's steamed bone 16.1
			Soluble bone No. 4, tankage, 9:1.......... 4.5
3	6	28.7	Packer's steamed bone 14.3
			Soluble bone No. 4, tankage, 9:1.......... 3.5
4	6	26.7	Packer's steamed bone 14.5
			Soluble bone No. 4, tankage, 9:1..........11.4

Test No. 16, August 21 to 28, 1920

Comparison of packer's steamed bone and soluble bone, both flavored with tankage; basal ration, corn, wheat middlings and skimmilk.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	6	38 1	Packer's steamed bone, tankage, 9:1......... 2.4 Soluble bone No. 4, tankage, 9:1..........19.0
2	6	32.6	Packer's steamed bone, tankage, 9:1......... 5.8 Soluble bone No. 4, tankage, 9:1..........14.4
3	6	37.8	Packer's steamed bone, tankage, 9:1.........13.6 Soluble bone No. 4, tankage, 9:1.......... 9.8
4	6	33.7	Packer's steamed bone, tankage, 9:1......... 8.1 Soluble bone No. 4, tankage, 9:1..........20.0

Test No. 17, August 28 to September 6, 1920

Comparison of packer's steamed bone and soluble bone, both flavored with tankage; basal ration, corn, linseed oilmeal and tankage.

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	6	40.95	Packer's steamed bone, tankage, 9:1........ 4.7 Soluble bone No. 4, tankage, 9:1..........19.1
2	6	36.50	Packer's steamed bone, tankage, 9:1........ 6.0 Soluble bone No. 4, tankage, 9:1..........15.3
3	6	40.57	Packer's steamed bone, tankage, 9:1........ 5.2 Soluble bone No. 4, tankage, 9:1..........24.5
4	6	37.43	Packer's steamed bone, tankage, 9:1........ 8.7 Soluble bone No. 4, tankage, 9:1..........15.0

Test No. 18, September 6 to 18, 1920

Lot No.	No. of pigs	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	6	45.2	Packer's steamed bone, tankage, 9:1......... 1.7 Soluble bone No. 4, tankage, 9:1..........35.6
2	6	44.0	Packer's steamed bone, tankage, 9:1......... 3.7 Soluble bone No. 4, tankage, 9:1..........30.7
3	6	44.7	Packer's steamed bone, tankage, 9:1......... 4.0 Soluble bone No. 4, tankage, 9:1..........33.1
4	6	41.5	Packer's steamed bone, tankage, 9:1......... 3.5 Soluble bone No. 4, tankage, 9:1..........34.2

Test No. 19, September 18 to October 29, 1920

Comparison of tankage and fish scrap as flavoring substances for a mineral supplement.

Lot No.	Ave. wt. of pigs Kg.	Grams eaten per pig per day
1	62.1	Soluble bone No. 4, tankage, 9:1 ....10.8 Soluble bone No. 4, fish, 9:1.................. 8.7
2	58.0	Soluble bone No. 4, tankage, 9:1..................13.9 Soluble bone No. 4, fish, 9:1................... 9.4
3	60.2	Soluble bone No. 4, tankage, 9:1.................. 7.8 Soluble bone No. 4, fish, 9:1...................20.5
4	57.3	Soluble bone No. 4, tankage, 9:1..................12.5 Soluble bone No. 4, fish, 9:1................... 8.4

A statement of the results of the above tests will be found on page 93.

EXPERIMENTS WITH CATTLE

The tests with cattle were conducted with mature, milking cows, dry-fed, and confined in a barnyard, and with calves and yearling heifers at pasture. As in the case of the work with pigs all supplements were self-fed in sheltered boxes.

Test No. 20, May 24 to 25, 1920

Comparison of mineral supplements mixed with salt; subjects, seven mature Holstein cows, average weight 1,126 pounds, average milk production 28 pounds per day.

Supplements	Grams eaten per cow per day
Special steamed bone, salt, 2:1	589
Rock phosphate, salt, 2:1	0
Precipitated bone, salt, 2:1	77
Precipitated calcium carbonate, salt, 2:1	536

Test No. 21, May 26 to 27, 1920

Repetition of Test No. 20; subjects and conditions same as above.

Supplements	Grams eaten per cow per day
Special steamed bone, salt, 2:1	374
Rock phosphate, salt, 2:1	4
Precipitated bone, salt, 2:1	0
Precipitated calcium carbonate, salt, 2:1	86

Test No. 22, May 29 to June 3, 1920

Special steamed bone and salt fed alone to cows; subjects and conditions same as above.

Supplements	Grams eaten per cow per day
Special steamed bone, salt, 2:1	349

Test No. 23, June 3 to 8, 1920

Special steamed bone and salt fed alone to cows; subjects and conditions same as above.

Supplements	Grams eaten per cow per day
Special steamed bone, salt, 4:1	436

Test No. 24, June 8 to 12, 1920

Special steamed bone fed alone to cows; subjects and conditions same as above.

Supplements	Grams eaten per cow per day
Special steamed bone, alone	117

Test No. 25, May 24 to 29, 1920

Comparison of slightly acidulated (soluble) bone preparations; subjects, 19 heifers, at pasture, average age 21 months, average weight 710 pounds.

Supplements	Grams eaten per head per day
Soluble bone No. 1, salt, 2:1	15
Soluble bone No. 2, salt, 2:1	14
Soluble bone No. 3, salt, 2:1	6
Soluble bone No. 4, salt, 2:1	5

Test No. 26, May 29 to June 5, 1920

Special steamed bone and salt fed alone to heifers; subjects and conditions same as above.

Supplements	Grams eaten per head per day
Special steamed bone, salt, 2.1	46

Test No. 27, June 5 to 12, 1920

Repetition of Test No. 23.

Supplements	Grams eaten per head per day
Special steamed bone, salt, 2:1	39

Test No. 28, May 24 to 29, 1920

Comparison of special steamed bone and calcium carbonates; subjects, 11 calves at pasture, average age 9 months, average weight 399 pounds.

Supplements	Grams eaten per head per day
Special steamed bone, salt, 2:1	15
Marl, salt, 2:1	3
Pulverized limestone, salt, 2:1	2
Precipitated calcium carbonate, salt, 2:1	2

Test No. 29, May 29 to June 5, 1920

Special steamed bone and salt fed alone to calves at pasture.

Supplements	Grams eaten per head per day
Special steamed bone, salt, 2:1	33

Test No. 30, June 5 to 12, 1920

Repetition of Test No. 26.

Supplements	Grams eaten per head per day
Special steamed bone, salt, 2:1	41

Test No. 31, July 28 to 31, 1920

Precipitated bone flour and salt, 4:1, fed to cattle of various ages.

Kind of cattle	No. of cattle	Average weight Lbs.	Grams eaten per head per day
Cows (in milk)	7	1,101	782
Heifers	20	777	54
Calves	5	615	88

Test No. 32

Comparison of packer's steamed bone and salt, 4:1, with special steamed bone and salt, 4:1, for cattle of various ages; cows, July 31 to August 7; heifers, July 31 to August 11; calves, August 2 to 11, 1920.

Kind of cattle	No. of cattle	Average weight Lbs.	Grams eaten per head per day: Packer's bone	Grams eaten per head per day: Special steamed bone
Cows (in milk)	7	1,101	146	39
Heifers	20	777	30	28
Calves	5	615	49*	81

*Probably not a fair test; this preparation almost all eaten before residue was weighed

Test No. 33, August 11 to 21, 1920

Repetition of Test No. 29.

Kind of cattle	No. of cattle	Average weight	Grams eaten per head per day: Packer's steamed bone	Special steamed bone
		Lbs.		
Cows (in milk)	7	1,101	128	61
Heifers	20	777	42	27
Calves	5	615	55	21

Test No. 34, September 18 to 21, 1920

Comparison of soluble bone No. 4 and packer's steamed bone, both mixed with salt, the subjects being 7 mature cows, dry-fed and confined to a barnyard.

Supplements	Grams eaten per cow per day
Soluble bone No 4, salt, 4:1	21.4
Packer's steamed bone, salt, 4:1	456.2

RESULTS WITH SWINE

In a test covering a period of 15 weeks special steamed bone, a clean and nearly odorless gelatine manufactory by-product, was the most palatable mineral supplement fed, followed, in decreasing order of palatability by precipitated bone, pulverized limestone, whiting, precipitated calcium carbonate, rock phosphate floats and marl. (Test No. 1.)

A comparison of special steamed bone with soluble (slightly acidulated) bone preparations showed that the latter are the more palatable. (Tests 2, 3, 7, 8, 9, 12, 13.)

A comparison of soluble bone preparations Nos. 1, 2, 3 and 4 showed that No. 4 was the most palatable, followed by No. 3. The method of preparation decreased the dust in the finely-ground bone, increased the solubility of the phosphorus, and increased the animal odor, which pigs undoubtedly like. (Tests 2, 3, 8, 9.)

The results of comparisons of packer's steamed bone and soluble steamed bone, both without flavoring substances, were divided, as to trend (Test 14), as also were the results of comparisons of packer's steamed bone alone with soluble bone and tankage (Test 15). Tests 16, 17 and 18, however, in which packer's steamed bone and tankage were compared with soluble steamed bone and tankage yielded evidence strongly in favor of the soluble bone preparation as the more palatable.

Tankage adds materially to the palatability of mineral substances with which it is mixed. (Tests 4, 5, 6.) It is more palatable than dried blood (Tests 10, 11), is probably more palatable than fish scrap (Test 19), and is more useful as a flavoring substance for mineral supplements for hogs than any other included in this study.

Coriander seed has some value as a flavoring substance in mineral supplements for hogs, but is too expensive to be used for this purpose, and is less palatable than is tankage. (Tests 6, 7.)

Molasses is liked by pigs, and increases the palatability of minerals with which it is fed. (Earlier studies.)

Salt adds some, but not much, to the palatability of a mineral supplement for swine. (Earlier studies.)

Humus (as used by feed manufacturers) makes no definite contribution to the palatability of a mineral supplement. (Earlier studies.)

Among other substances used in these tests which do not add materially to the palatability of mineral supplements for swine are anise, fenugreek, caraway and fennel seed, ginger, charcoal and ground alfalfa hay. (Tests 4, 5, 6, 7.)

During the discomfort of hot weather pigs have less appetite for minerals than in cooler weather. (Tests 8, 9.)

A light, dusty powder is not palatable to pigs. Apparently they do not like to breathe dust. If very finely divided material is to be fed to pigs it should be so prepared as not to be dusty. Coarse and gritty mineral substances are not avoided by pigs; in fact, they seem distinctly to like them.

Any substance which pigs like adds more to the palatability of a mineral supplement if it be not also contained in the basal ration.

Pigs which are out of condition may manifest an abnormal appetite for mineral feeds; thus, in one of our tests (No. 4) five cull pigs, each weighing about 100 pounds, ate 1,555 grams of steamed bone and tankage (9:1) in one day.

A practical method of feeding a mineral supplement to hogs is to offer it mixed with one-ninth as much tankage, in a self-feeder.

RESULTS WITH CATTLE

Special steamed bone is more palatable to cows than is precipitated calcium carbonate, precipitated bone phosphate, or rock phosphate. (Tests 17, 18.) This bone preparation was also more palatable to heifers than was marl, pulverized limestone or precipitated calcium carbonate (Test 25), and appeared to be most palatable when fed in the proportion of four parts of the bone to one of salt. (Tests 19, 20, 21.)

In a comparison of soluble bone preparations Nos. 1, 2, 3 and 4, heifers ate most of No. 1, which contained the least acid, and less of each of the others, in order of increasing amount of acid in the preparations. (Test 22.)

Ordinary packer's steamed bone is more palatable to cattle than is special steamed bone, though the latter is taken freely (Tests 29, 30), and is more palatable, also, than soluble bone No. 4, which is especially well taken by hogs.

Cattle which have not had access to bone preparations for a time may eat inordinate quantities of such feeds until their appetites are satisfied; thus, (Test 17) each of seven cows ate, on an average, 1,202 grams of mineral supplement in 1 day. The large consumption of mineral substance by these same cows in other tests (Nos. 18, 19, 20, 28) must be considered as due in part to a craving probably caused by the method of feeding, since they had been maintained for a protracted period on dry feeds and silage, without grass.

A practical method of feeding mineral supplements to cattle of all ages is to offer the same mixed with one-fourth as much common salt, in self-feeders, (Tests 29, 30).

RESULTS WITH HORSES

Our experience in the feeding of mineral supplements to horses is very slight. We have found that some horses, at least, will readily take precipitated bone and special steamed bone, mixed with salt, and others will not do so; also that these preparations may be successfully fed mixed with the grain. So far as our experience goes horses will not eat packer's steamed bone, as will cattle and hogs.

A discussion of the practical bearings of this subject will be found in the Monthly Bulletin of the Experiment Station for July, 1920. This treatment, however, does not include a consideration of those tests here reported as having been conducted subsequent to June 16, 1920. These later tests show, especially, that ordinary fertilizer steamed bone is readily eaten by both cattle and swine, and that soluble bone No. 4 is more palatable to hogs than either the special or the packer's steamed bone.

6. THE ALKALI RESERVE OF SWINE AS AFFECTED BY CEREAL FEEDING AND MINERAL SUPPLEMENTS

It is common knowledge among students of animal nutrition that cereal rations are characterized by excess of acid as compared with basic mineral elements, and by a marked deficiency of calcium. A question remains, however, as to whether this potential acidity of cereal rations is of such degree as to constitute it a practical consideration, and especially as to the extent to which this acidity should be considered as merely incidental to the calcium shortage.

In the investigation of the physiological significance of the potential acidity of cereal rations it becomes a matter of much interest to determine the influence of this factor in relation to the composition and functional efficiency of the blood and tissues. A significant and fundamental matter in this connection is the maintenance of the alkali reserve, which may be considered, in general terms, as composed of those constituents of the body which can be used for acid neutralization. In the method of estimation of Van Slyke, Stillman and Cullen,* which was used in this study, the alkali reserve is determined as the bicarbonate concentration of the blood plasma.

Ammonia and acidity were estimated by the methods of Folin, and hydrogen ion concentration by the colorimetric method of Clark and Lubs, using the colored screen and the comparator.

The blood samples were taken from the tail, the handling of the subjects being successfully accomplished by the use of a crate devised for hog-cholera serum work. The tail was shaved, the end clipped off, and the blood drawn through a 5 cm. funnel into a 50 cc. centrifuge tube where it was collected under a 0.5 cm. layer of liquid petrolatum (Squibb). The funnel was fitted to the tube with a two-hole rubber stopper, and the funnel and tube together contained powdered potassium oxalate equal to 0.1 percent of the blood drawn. The tail was held inside the funnel, with the bleeding tip within 1 or 2 cm. of the bottom, to minimize possible loss of carbon dioxide.

In this study two pigs were fed a cereal ration composed of corn 7 parts, wheat middlings 1 part, and linseed oilmeal 1 part, with salt (NaCl) weighed separately at a rate of 2.2 gm. per kilo of feed. The two pigs weighed 65.0 and 62.4 kilos, respectively, on October 14, at the beginning of the experimental treatment,

*Van. Slyke, D. D., Stillman, E., and Cullen, G. E., J. Biol. Chem., 1919, xxxviii, 167.

and on January 2, 112.3 and 110.0 kilos, respectively. The experiment terminated on January 3. The pigs were fed in metabolism crates, and cared for as in metabolism experiments.

In the first period the cereal ration was fed alone for 33 days, during the last 7 of which alkali reserve estimations on the blood plasma were made twice on each subject.

In the second period there was then added to the cereal ration calcium carbonate in amounts equivalent to 200 mg. of calcium per kilo of live weight of the pigs. This treatment was continued for 25 days, during the last 12 of which alkali reserve estimations were made on the two subjects three and four times, respectively, at intervals as shown in Table I.

In the third period the mineral supplement was changed to precipitated bone phosphate, which is largely in the dicalcic form, and which was fed in amounts furnishing, as before, 200 mg. of calcium per kilo of live weight. This treatment was continued for 23 days, during the last 13 of which alkali reserve estimations were made four times on each subject. The condensed data of the experiment will be found in Table I. Alkali reserve estimations were made on the days indicated, while estimations of urinary acid, ammonia, and hydrogen ion concentration were made daily during the greater part of the study and on alternate days during the remainder.

The data show that by the addition of calcium carbonate to a cereal ration the alkali reserve of the blood plasma was increased 10.1 and 10.8 percent, with the two pigs, above that which prevailed during the feeding of the cereal ration alone; and that then, by the substitution of precipitated bone phosphate for the calcium carbonate, the alkali reserve was reduced 14.8 and 15.4 percent, with the two subjects, to figures which are distinctly lower, in each case, than those obtained from the same individual on the cereal ration. The estimations of acidity, ammonia, and hydrogen ion concentration in the urine vary, as affected by the mineral supplements, in a manner concordant with the alkali reserve estimations, which they serve to confirm. The separate estimations of urinary acidity reveal marked daily and enormous individual variation in the details of the eliminative function.

The alkali reserve of the blood plasma of swine, therefore, is susceptible of variation, and may be either increased or decreased by the use of mineral supplements added to a cereal ration in such quantities as might be used in practical feeding. Since these variations would in all probability be followed, in time, by variations in the other alkali reserves of the body, it is more than likely that changes of body function would result. These might be favorable or unfavorable in accord with the ration and mineral supplements used.

TABLE I.—EFFECTS OF CEREAL RATION AND MINERAL SUPPLEMENTS ON BLOOD PLASMA AND URINE OF SWINE

Pig No.	Treatment	Date of estimation	Blood plasma: Molecular concentration of CO_2 as bicarbonate	Blood plasma: CO_2 as bicarbonate	24 hr. urine: Acidity	24 hr. urine: Ammonia	24 hr. urine: H ion concentration
				Vol. percent	*cc. 0.1 N*	*cc. 0.1 N*	*pH*
		1919					
1	Basal ration of cereals........	Nov. 11	0.0297	66.5	....	....	....
1	Basal ration of cereals..	Nov. 17	0.0314	70.3	....	....	....
Average......			0.0306	68.4	255 (8)*	4.18 (8)	7.1 (8)
1	Calcium carbonate...........	Nov. 29	0.0338	75.7	....	....	....
1	Calcium carbonate...........	Dec. 3	0.0354	79.3	....	....	....
1	Calcium carbonate...........	Dec. 9	0.0327	73.2	....	....	....
1	Calcium carbonate...........	Dec. 11	0.0328	73.5	....	....	....
Average.................................. ...			0.0337	75 4	—49 (13)	1.71 (13)	7.7 (13)
1	Precipitated bone phosphate	Dec. 22	0.0269	60.3	....	....	....
1	Precipitated bone phosphate	Dec. 26	0 0282	63.2	....	....	....
		1920					
1	Precipitated bone phosphate	Jan. 2	0.0295	66.1	....	....	....
1	Precipitated bone phosphate	Jan. 3	0.0303	67.9	....	....	....
Average.......................			0.0287	64.4	705 (15)	4.01 (15)	6.36 (15)
		1919					
2	Basal ration of cereals........	Nov. 12	0.0323	72.3	....	....	....
2	Basal ration of cereals........	Nov. 17	0.0323	72.4	....	....	....
Average....................................			0.0323	72.4	638 (8)	4.10 (8)	6.5 (8)
2	Calcium carbonate...........	Nov. 29	0.0350	78.4	....	....	....
2	Calcium carbonate...........	Dec. 3	0.0355	79.5	....	....	....
2	Calcium carbonate...........	Dec. 9	0.0370	82.9	....	....	....
Average....................................			0.0358	80.3	—29 (13)	1.06 (13)	7.6 (13)
2	Precipitated bone phosphate	Dec. 22	0.0306	68.5	....	....	....
2	Precipitated bone phosphate	Dec. 26	0.0314	70.3	....	....	....
		1920					
2	Precipitated bone phosphate	Jan. 2	0.0281	62.9	....	... ...	....
2	Precipitated bone phosphate	Jan. 3	0.0313	70.1	....	... .	....
Average.........................			0.0303	68.0	1,707 (15)	3.89 (15)	5.57 (15)

*The numbers in parentheses indicate the number of daily estimations averaged.

CONCLUSION

The alkali reserve of the blood plasma of swine may be significantly increased by the feeding of the potentially basic precipitated calcium carbonate, or decreased by the feeding of the potentially acid precipitated calcium phosphate, when these substances are fed as supplements to a cereal ration in quantities such as might be used in practical feeding.

Note: The practical bearings of the subject of mineral nutrients for farm animals have been recently discussed in the Monthly Bulletin of the Ohio Experiment Station for July, 1920.